The Quantum World, the Mind, and the Cookie Cutter Paradigm

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The problem of making sense of quantum mechanics is as much a psychological problem as it is a physical one. There is a conflict between (i) the spatiotemporal structure of the quantum world and (ii) the manner in which the phenomenal world is constructed by our minds and/or brains. Both are examined in detail. Unlike the quantum world, the phenomenal world conforms to the cookie cutter paradigm, according to which the synchronic multiplicity of the world rests on surfaces that carve up space much as cookie cutters carve up rolled-out pastry. The attempt to model the physical world in conformity with this paradigm gives rise to pseudo-problems that foil our attempts at making sense of the quantum world. The fact that quantum mechanics, the fundamental theoretical framework of contemporary physics, is essentially an algorithm for calculating the probabilities of measurement outcomes does indeed give rise to genuine problems, but their solution requires the rejection of unwarranted assumptions rather than the making of further such assumptions. The place of causal stories in a world governed by quantum laws is examined, and it is argued that presentism is inconsistent not only with the "block universe" of special relativity but also with the other corner stone of contemporary physics, quantum mechanics. Finally, the conclusions of this essay are situated within the context of the Vedantic theory of existence set forth in a companion essay (Mohrhoff, 2007).

1 Introduction

Quantum mechanics (QM), the general framework of contemporary physics, is an incredibly successful theory. No experiment, no observation, has ever given the lie to it. But if it is not lying, what does it tell us about the physical world? This question is the focus of a controversy that even after three quarters of a century shows no sign of abating.[1]

The purpose of this essay is to show that the problem of making sense of QM is as much a psychological problem as it is a physical one. There is a conflict between the spatiotemporal structure of the quantum world and the way in which the phenomenal world (particularly its visual aspect) is constructed by our brains and/or minds. Unlike the

1 "[O]ne can check that not a year has gone by in the last 30 when there was not a meeting or conference devoted to some aspect of the quantum foundations. . . Go to any meeting, and it is like being in a holy city in great tumult. You will find all the religions with all their priests pitted in holy war — the Bohmians, the Consistent Historians, the Transactionalists, the Spontaneous Collapseans, the Einselectionists, the Contextual Objectivist, the outright Everettics, and many more beyond that. They all declare to see the light, the ultimate light. . ." (Fuchs, 2002).

quantum world, the phenomenal world conforms to a principle I have dubbed "cookie cutter paradigm" (CCP), according to which the synchronic multiplicity of the world — its multiplicity at any one time — rests on surfaces that carve up space much as cookie cutters carve up rolled-out pastry.

A common entry point into the weird world of QM is the by now well-known two-slit experiment with electrons. Its discussion in Section 2 prepares us for Nature's fuzziness — both the why and the how of it (Section 3) — and the central role that measurements play in the fundamental theoretical framework of physics (Section 4). As a consequence of Nature's fuzziness, the reality of spatial distinctions is both relative and contingent (Section 5), and the spatiotemporal differentiation of the physical world does not go "all the way down" (Section 6). This has implications that go counter to some of our deepest convictions about matter and physical space (Section 7). The top-down structure of the physical world (Section 8), for instance, strikes us as preposterous. By contrasting the structure of the phenomenal world with that of the physical world, and by demonstrating how the CCP foils our attempts to make sense of the latter, we come to understand why this is so (Section 9). The attempt to construct (theoretical models of) the physical world in conformity with the CCP gives rise to pseudo-problems and gratuitous solutions (Section 10). The real problem is discussed in Section 11. Its solution calls for the rejection of unwarranted assumptions that are all but universally made, such as the intrinsic and complete spatiotemporal differentiation of the physical world. Section 12 examines the place of causal stories in a world governed by the laws of QM, and Section 13 explains why the idea that some things exist not yet and others exist no longer is as true (psychologically speaking) and as false (physically speaking) as the idea that a ripe tomato is red. Section 14, finally, situates the conclusions of the present essay within the context of the Vedantic theory of existence that is set forth in a companion essay (Mohrhoff, 2007).

2 "The Most Beautiful Experiment in Physics"[2]

The mathematical formalism of QM, the fundamental theoretical framework of contemporary physics, is an algorithm for calculating the probabilities of possible measurement outcomes on the basis of actual outcomes. This algorithm rests on two simple rules. Suppose that you want to calculate the probability of a particular outcome of a measurement M_2 given the outcome of an earlier measurement M_1. This can be done by choosing any sequence of measurements that may be made in the meantime, assigning to each possible sequence a complex number called "amplitude," and doing either of the following:

- Rule A: if the intermediate measurements are made (or if it is merely possible to find out what their outcomes would have been if they had been made), first *square* the absolute values of the amplitudes of all possible sequences of outcomes and then *add* the results.

2 According to a poll conducted by *Physics World* (Crease, 2002).

- Rule B: if the intermediate measurements are not made (and if it is impossible to find out what their outcomes would have been if they had been made), first *add* the amplitudes of all possible sequences of outcomes and then *square* the absolute value of the result.

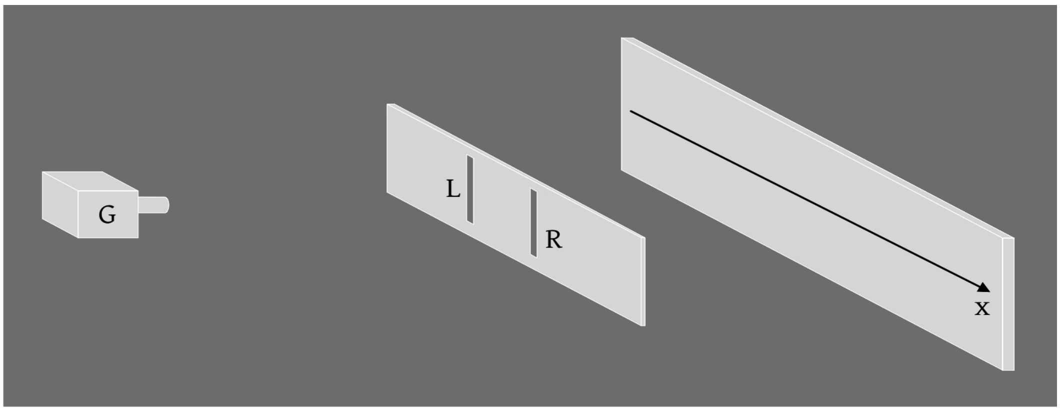

Figure 1. The set-up: an electron gun G, a plate with two parallel slits L and R, and a backdrop at which electrons are detected. The probability of detection is a function of the detector position x.

Let us apply these rules to the two-slit experiment with electrons (Figure 1), which according to Richard Feynman "has in it the heart of quantum mechanics" and "is impossible, absolutely impossible, to explain in any classical way" (Feynman et al., 1965, Sec. 1–1).[3] We consider a single intermediate measurement with two possible outcomes, indicating the slit through which the electron went. The final outcome, whose probability we wish to calculate, consists in the electron's detection at a particular location at the backdrop.[4] If we plot this probability as a function of the detector position x, we obtain the two graphs shown in Figure 2. The probability distribution $A(x)$, calculated according to Rule A, is the sum of two distributions: the probability with which an electron is detected after it went through the left slit (L), and the probability with which it is detected after it went through the right slit (R). This is what one expects from standard probability theory, according to which an event that can come to pass in either of two ways, with respective probabilities p_1 and p_2, comes to pass with probability

$$p = p_1 + p_2 \,.$$

3 This classic *gedanken* experiment was first realized in 1961 (Jönsson, 1961, 1974).

4 The initial outcome, on the basis of which this probability is calculated, consists in the electron's launch in front of the slit plate. If the electron gun in front of the plate is the only source of free electrons, this outcomes is indicated by the detection of an electron behind the plate.

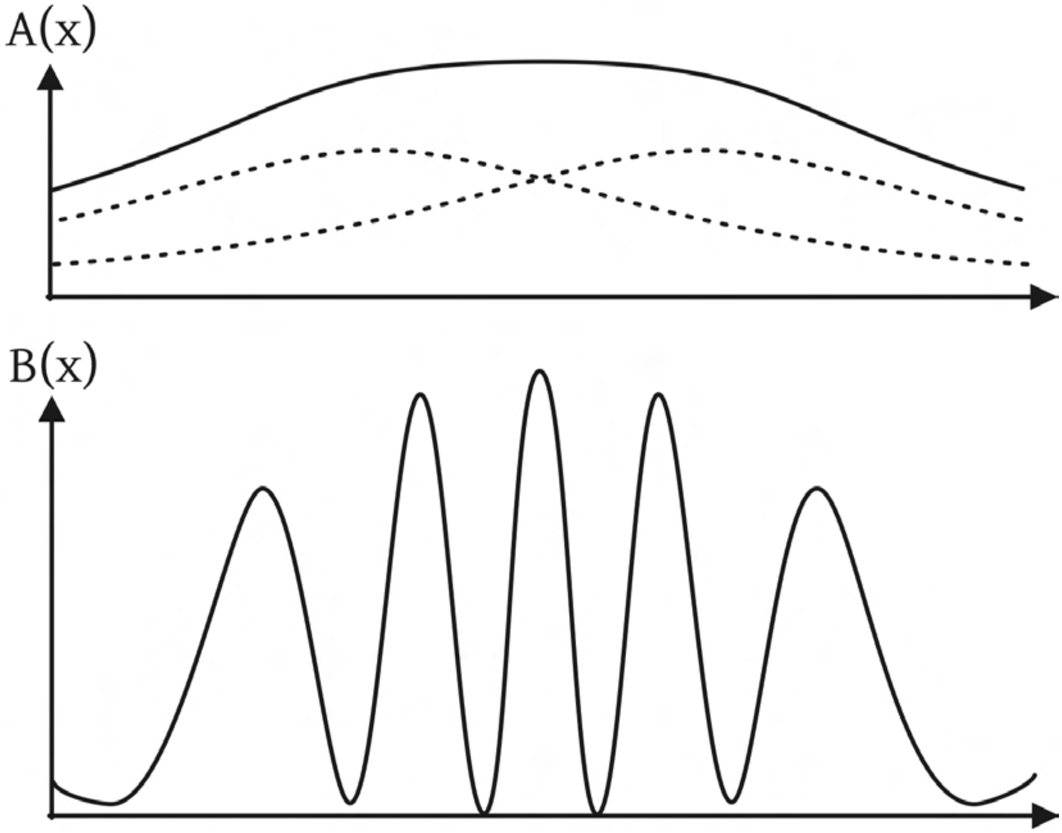

Figure 2. Above: the probability of detection calculated according to Rule A (as a function of the detector position x) is the sum of two graphs (dotted), each giving the distribution of electrons that went through a particular slit — either L or R. Below: the probability of detection calculated according to Rule B.

Let us try to understand what happens under the conditions stipulated by Rule B. We will assume, to start with, that

- each electron goes through a particular slit (either L or R),
- and that the behavior of electrons that go through the left (or right) slit does not depend on whether the right (or left) slit is open or shut.

To keep the language simple, we shall say that each electron leaves a mark where it is detected at the backdrop. If the first assumption is true, then the distribution of marks that we observe when both slits are open is given by

$$n(x)=n_L(x)+n_R(x)\,,$$

where $n_L(x)$ and $n_R(x)$ are the distributions of marks made by electrons that went through L and R, respectively. If the second assumption is true, then we can observe $n_L(x)$ by keeping R shut, and we can observe $n_R(x)$ by keeping L shut. What we observe when R is shut is the left dotted hump in Figure 1, and what we observed when L is shut is the right dotted hump. Hence if both assumptions are true, we will observe the sum of these two humps — distribution $A(x)$. But this is what we observe under the conditions stipulated by Rule A! Under the conditions stipulated by Rule B we obtain the remarkably different distribution $B(x)$.

Thus at least one of the two assumptions is false. (If the first is false, then the second is vacuous.) There is an alternative to nonrelativistic QM, known as Bohmian mechanics (BM), according to which only the second assumption is false (Bohm, 1952): all electrons follow well-defined paths, which "exhibit" strange wiggles, and which cluster at the backdrop so as to produce the observed distribution $B(x)$.

What causes the wiggles? BM explains this by positing the existence of a "pilot wave" that guides electrons by exerting on them a force. If both slits are open, it passes through both slits and interferes with itself. As a result, it guides electrons along wiggly paths.

The reason why, according to BM, electrons emerging from the same slit or coming from the same source arrive in different places, is that they start out in slightly different directions and/or with slightly different speeds. If we had precise knowledge of these initial values, we could predict each electron's future motion exactly. But QM says that we can't, and since BM is offered as a theory that makes the same predictions as QM, it too must say that we can't. Unlike QM, BM asserts that well-defined electron paths and exact initial values exist but that they are *hidden* from us.

BM has well-known drawbacks: For one thing, a Bohmian alternative to *relativistic* QM remains to be found.[5] For another, the pilot wave associated with a physical system S with *n* degrees of freedom "propagates" in an *n*-dimensional abstract space, which can be identified with physical space only if S is a single particle.[6] What is worse, on this theory energy and momentum and spin and every particle property other than position are *contextual*. This means that the outcome of a measurement of any of these variables generally depends not only on the particle's unobservable exact position and the unobservable pilot wave but also on which *other* measurements are performed at the same time (Albert 1992, Chap. 7).[7] Finally, BM fails to tell us *why* hidden variables are hidden, even though the question has a simple answer: they are "hidden" because *they do not exist*.

To my mind, the proper way to discover what QM is trying to tell us, is (i) to assume nothing beyond the common denominator of *all* suggested interpretations of the formal-

5 According to Albert (1992, p. 160), this won't happen: "there can't possibly be any such thing as a Lorentz-covariant relativistic extension of this sort of a theory."

6 This is a straightforward consequence of the fact that the quantum-mechanical wave function is a tool for calculating probabilities: the joint probability, say, of detecting one particle at (*x,y,z*) and another at (*x',y',z'*) is a function of the six coordinates (*x,y,z,x',y',z'*). By the way, this is one of many possible illustrations that the features of the mathematical formalism of QM are readily understood if the formalism itself is understood as a probability algorithm (Mohrhoff, 2002d, 2004c).

7 This certainly dashes the hope that a theory with hidden variables might produce an ontology free of those pesky references to "measurement."

ism[8] — that is, nothing beyond the minimum needed to relate theory and experiment — and (ii) to analyze the formalism's *testable* predictions in a variety of measurement contexts. Once we have a clear view on the ontological implications of the testable predictions, we may, if we are still in the mood for it, embroider them with unverifiable stories.

Back to our experiment! If the conditions stipulated by Rule B are met, we must deny ourselves the assumption that the electron nevertheless went through a particular slit. We must not associate truth values ("true" or "false") with the propositions P_L = "the electron went through L" and P_R = "the electron went through R." Lacking truth values, these propositions are meaningless. We may paraphrase this by saying that the electron went through both slits, provided we are careful about the ambiguity of this phrase. It cannot be equivalent to the conjunction $P_L \& P_R$, for if the conjoined propositions lack truth values, the conjunction is equally meaningless. Saying that the electron went through both slits can only mean that it went through L&R — *the regions defined by the slits considered as an undivided whole* — rather than through a particular slit (either L or R).

Note that this cannot be construed as saying that the electron has two parts, one that goes through L and another that goes through R. In fact, the question of parts does not arise, for what goes through L&R (without going through a particular slit) is the electron's *position*, and a position isn't the kind of thing that has parts.[9] Nor should it be construed as saying that the electron passes through the slit plate as a *wave*, with different parts of the wave passing through different slits. The "parts" of a probability distribution are not parts of a physical object, nor is the probability with which something happens in a given region of space something that is present in that region, nor do the "parts" of the wave function associated with a physical system consisting of two or more particles "exist" in physical space, as you will remember from Note 6.

3 A Fuzzy World

One of the more acute dilemmas that led to the fall of classical mechanics and the invention of QM was posed by the stability of matter — that is, the existence of things that (i) "occupy" finite volumes of space, (ii) are composed of a large but finite number of unextended things (particles that do not "occupy" space),[10] and (iii) are stable: they neither explode nor collapse as soon as they come into being. Thanks to QM, we know now that

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8 Readhead (1987, p. 44) calls this the "minimal instrumentalist interpretation" of QM.

9 Analogous experiments have been performed with C_{60} molecules using a grating with 50 nm wide slits and a period of 100 nm, instead of a plate with only two slits (Arndt et al., 1999). The sixty carbon nuclei of C_{60} are arranged like the corners of soccer ball just 0.7 nm across. We don't picture parts of such a molecule as first getting separated by many times 100 nm and then getting reassembled into a ball less than a nanometer across.

10 One sometimes comes across claims to the effect that the electron is actually made up of an infinite number of particles — the "bare" electron plus an infinite swarm of "virtual" photons and "virtual" particle-antiparticle pairs, which are said to be "vacuum fluctuations" of the surrounding radiation and matter fields. This kind of story is the typical reward for the transmogrification of a probability calculus into some physical state of affairs.

the existence of such things hinges on the *objective fuzziness* of both the relative positions and the relative momenta of their constituents.[11] This is what "fluffs out" matter.

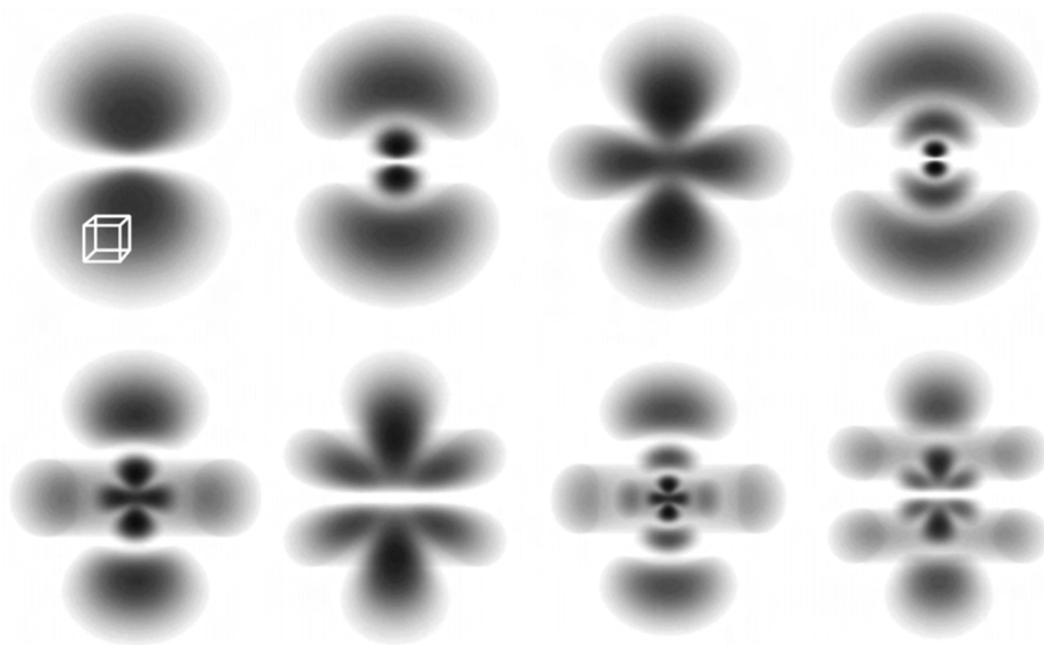

Figure 3. Each of these "clouds" represents the fuzzy position of the electron relative to the nucleus in a stationary state of atomic hydrogen. Each volume element dx dy dz is assigned an opacity proportional to the probability of detecting the electron inside. The darkness of each image pixel renders the integrated opacity along a line of vision through the cloud.

How does one define and quantify a fuzzy observable? The answer is: by assigning probabilities to the the possible outcomes of an unperformed measurement of such an observable (Mohrhoff, 2000, 2001b, 2004a, 2005). And whence the need to assign probabilities *counterfactually,* to the possible outcomes of *unperformed* measurements? Consider Figure 3. These cloudlike images illustrate the fuzzy position of the electron relative to the nucleus in various stationary states[12] of atomic hydrogen. Imagine a bounded region V of space like the little box inside the first "cloud." If we integrate the density $\rho(x,y,z)$ of the cloud over V, the result we get is the probability with which the electron *would* be found in V if a measurement capable of determining the truth value of the proposition "the electron is in V" *were* made. As long as the hydrogen atom is "in"

11 The English term commonly used in this context — "uncertainty" — mistranslates Heisenberg's original term *Unschärfe*, the literal meaning of which is "fuzziness." The stability of matter hinges on the objective fuzziness of internal relative positions and momenta, not on our subjective uncertainty about the values of these observables.

12 In the peculiar terminology of QM, a "state" is a probability algorithm. If it is stationary, then the probabilities it assigns do not depend on the time of the measurement to the possible outcomes of which they are assigned.

one of these "states," that proposition lacks a truth value. The electron is neither inside nor outside V. If it were inside, the probability $p(V)$ of finding it there would be 1, and if it were outside, $p(V)$ would be 0, neither of which is the case. On the other hand, if the measurement is actually made, that proposition has a truth value: the electron is either inside or outside V. Thus in order to quantify a fuzzy position, we must assume that a measurement is made, and in order to interpret a particular quantification — a particular ρ — as representing the electron's fuzzy position relative to the nucleus, we must assume that no measurement is made. If we want to describe a fuzzy position "as it is," without changing it, we must describe it by assigning probabilities to the possible outcomes of *unperformed* measurements.

4 The importance of measurements

Under the conditions stipulated by Rule B, the propositions "the electron went through L" and "the electron went through R" lack truth values. By the same token, as long as the fuzzy position of the electron relative to the nucleus is described by ρ, the proposition "the electron is in V" is neither true nor false. We thus need a criterion that tells us when a proposition has a truth value, when a variable has a value, and when a question has an answer.

There is a notion that probability 1 is sufficient for "is" or "has." According to it, the electron is in V if the probability of finding it there is 1. (This is not the same as saying, as we did, that if the electron is in V then the probability of finding it there is 1.) To see that that notion is wrong, let us ask why the probability of finding a given particle in the union $A \cup B$ of two disjoint regions A and B, calculated according to the standard rule due to Max Born, is equal to the probability of finding the particle in A plus the probability of finding the particle in B:

$$p(A \cup B) = p(A) + p(B).$$

The answer would be self-evident if the particle's position were sharp. In that case the particle would be either in A or in B whenever it is in $A \cup B$. But that would mean that $p(A)$ and $p(B)$ are subjective, and this is wrong. Subjective probabilities are ignorance probabilities. They enter the picture when relevant facts are ignored, and they disappear when all relevant facts are taken into account. The "uncertainty" principle guarantees that quantum-mechanical probabilities cannot be made to disappear. The reason this is so is not a lack of knowledge but a lack of relevant facts. The laws of QM correlate measurement outcomes, so that actual outcomes can be used to assign probabilities to possible outcomes, but even the totality of outcomes relevant to predicting the outcome of a particular measurement is generally insufficient for predicting this outcome with certainty.

To see that the answer is *not* self-evident, imagine two perfect (one hundred percent efficient) detectors $D(A)$ and $D(B)$ each monitoring one of those regions. If both $p(A)$ and $p(B)$ are greater than 0 (and therefore less than 1), then it isn't certain that $D(A)$ will click, and it isn't certain that $D(B)$ will click. Yet if $p(A \cup B)$ equals 1, then it *is* certain that *either* $D(A)$ *or* $D(B)$ will click. What makes this certain? The answer lies in the fact that quantum-mechanical probability assignments are invariably made on the (tacit) assumption that a measurement is *successfully* made: there is an outcome. So there is no mystery here, but the upshot is that QM gives us probabilities with which this or that result is obtained in a successful measurement, *not* probabilities with which this or that property, value, or truth value is possessed, regardless of measurements.

If probability 1 is not sufficient for "is" or "has," then what is? As far as unadulterated, standard QM is concerned — no surreal particle trajectories *à la* Bohm (1952), no nonlinear modifications of the Schrödinger equation *à la* Ghirardi, Rimini, and Weber (1986) or Pearle (1989), no extraneous axioms like the traditional eigenstate-eigenvalue link (van Fraassen, 1991, pp. 241, 247, 280, 314) or the modal semantical rule (Dieks, 1989, 1994) — then the only condition available is to be measured. To paraphrase a well-known dictum due to Wheeler,[13] no property (or value) is a possessed property unless it is a measured property or value — unless, that is, its possession can be inferred from a property- or value-indicating event or state of affairs ("measurement"). In the quantum world, properties and values are *extrinsic* in this particular sense (Mohrhoff, 2000, 2002c, 2004b, 2005). In the quantum world, to *be* is to be *measured*.[14]

5 The Relative and Contingent Reality of Spatial Distinctions

Take another look at Figure 3, and once again imagine a bounded region V somewhere inside one of those clouds. You will remember that as long as this particular probability distribution represents the position of the electron relative to the proton, the electron is

13 "No elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon" (Wheeler, 1983). This recapitulates an important aspect of the views of Niels Bohr, which have inspired several interpretations of QM, which are collectively known as the "Copenhagen interpretation."

14 This amply justifies Bohr's insistence that, out of relation to experimental arrangements, the properties of quantum systems are undefined (Petersen, 1968, pp. 110–1, 145). At present, however, most physicists and philosophers of science tend to agree with Bell (1990) that "[t]o restrict quantum mechanics to be exclusively about piddling laboratory operations is to betray the great enterprise." For them, to solve the problem posed by the special status accorded to measurements by the fundamental theoretical framework of physics — the so-called "measurement problem" — "means to design an interpretation in which measurement processes are not different in principle from ordinary physical interactions," as an anonymous referee once put it to me. Instead of leading to a solution, this strategy merely sweeps the problem under the rug. For one thing, what could be meant by an "ordinary physical interaction"? Interactions can only be described by their effects, and these are correlations between the probabilities of the possible outcomes of *measurements* performed on the interacting systems. For another, the unperformed measurements that play a key role in the mathematical description of fuzzy states of affairs have little to do with "piddling laboratory operations," nor are the latter the sole referents of "measurement" in axiomatizations of QM. While it is true that the dependence of the existence of truth values on truth-value-indicating events is most obvious in a suitably equipped laboratory, it does not follow that such events occur only in laboratories. Any event from which either the truth or the falsity of a proposition of the form "system S has property P" can be inferred qualifies as a measurement.

neither inside V nor outside V. Yet being inside or being outside are the only relations that can hold between an electron (or the center-of-mass position of any composite object) and a region of space. If neither relation holds, this region simply does not exist as far as the electron is concerned. But conceiving of a region R is tantamount to making the distinction between "inside R" and "outside R." Hence we may say that the distinction we make between "inside R" and "outside R" is a distinction that the electron does not make. Or we may say that the distinction we make between "the electron is inside R" and "the electron is outside R" is a distinction that Nature does not make. It corresponds to nothing in the actual world. It exists solely in our heads.

The long and the short of it is that the reality of spatial distinctions is relative and contingent: *relative* because such a distinction may exist for a given object at a given time and not exist for a different object at the same time or for the same object at a different time;[15] and *contingent* because the existence of a spatial distinction, for a given object O at a given time *t*, depends on whether the proposition "O is in V at *t*" has a truth value, which in turn depends on whether a truth value is indicated. The reality of spatial distinctions *supervenes* (in this particular sense) on property-indicating events or states of affairs.[16]

It follows that a detector[17] performs two necessary functions: it indicates the truth value of a proposition of the form "O is in W," and by realizing W (or the distinction between "inside W" and "outside W") it makes the predicates "inside W" and "outside W" available for attribution. Unless a region of space is realized by being the sensitive region of a detector, it does not exist, and unless a particle's presence in or absence from a realized region is indicated, this region — or the distinction we make between being inside and being outside — does not exist as far as the particle is concerned.

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15 If we put a dim light source behind the slit plate, an electron may or may not scatter a photon as it emerges from the slits. A scattered photon contains information about where it was scattered, and thus about the slit taken by the electron by which it was scattered. If two electrons pass the slit plate simultaneously but only one of them scatters a photon, then one went through a particular slit while the other passed the slit plate without going through a particular slit. In this case the distinction between L and R is simultaneously real for one electron and not real for another.

16 Suppose that W is a region disjoint from V, and that O's presence in V is indicated. Isn't O's absence from W indicated as a result? Are we not entitled to infer that the proposition "O is in W" has a truth value (namely, "false")? Because the reality of spatial distinctions is relative and contingent, or because it supervenes on property-indicating events or states of affairs, the answer is negative. Regions of space do not exist "by themselves." The distinction we make between "inside W" and "outside W" has no reality *per se*. If W is not realized (made real) by being the sensitive region of an actually existing detector (in the broadest sense of the word: anything capable of indicating the presence of something somewhere), then it does not exist, and if it does not exist, then the proposition "O is in W" cannot be in possession of a truth value. Neither W nor its complement is available for attribution to O. All we can infer from O's indicated presence in V is the truth of a *counterfactual*: if W were the sensitive region of a detector D, then O would not be detected by D.

17 A perfect detector, to be precise; if D is less than 100% efficient, the absence of a click does not warrant the falsity of "O is in W."

6 The Incomplete Spatiotemporal Differentiation of the Physical World

Let $\mathbb{R}^3(O)$ be the set of (conceivable) exact positions relative to an object O. Since no material object ever has a sharp position,[18] we can conceive of a partition of $\mathbb{R}^3(O)$ into finite regions that are so small that none of them is the sensitive region of an actually existing detector.[19] Hence we can conceive of a partition of $\mathbb{R}^3(O)$ into sufficiently small but finite regions V_k of which the following is true: there is no object Q and no region V_k such that the proposition "Q is inside V_k" has a truth value. In other words, there is no object Q and no region V_k such that V_k exists for Q. But a region of space that does not exist for *any* material object, does not exist *at all*. The regions V_k represent spatial distinctions that Nature does not make. They correspond to nothing in the physical world. It follows that the spatial differentiation of the physical world is incomplete — it does not go all the way down.

The same goes for time. The times at which observables possess values, like the possessed values themselves, must be indicated in order to exist. Clocks are needed not only to indicate time but also, and in the first place, to make times available for attribution to indicated values. Since clocks indicate times by the positions of their hands,[20] and since exact ("sharp") positions do not exist, neither do exact times. From this the incomplete temporal differentiation of the physical world follows in exactly the same way as its incomplete spatial differentiation follows from the nonexistence of exact positions. Neither the spatial nor the temporal differentiation of the world goes all the way down.

7 Fundamental Particles and the Nature of Physical Space

According to the well-established laws of particle physics — the so-called "standard model" — quarks (which make up, among other things, the proton and the neutron) and leptons (which include, among other things, the electron) are fundamental in the sense that they lack structure. An object that lacks structure also lacks spatial extent; it doesn't "occupy space." If such an object has a form, it will be that of a geometrical point. But does it have a form? What does the theory have say on this issue? Precisely nothing.

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18 In a nonrelativistic world, this is so because the exact localization of a particle implies an infinite momentum dispersion and thus an infinite mean energy. In the actual, relativistic world, the attempt to produce a strictly localized particle instead results in the creation of particle-antiparticle pairs.

19 Since the relative positions of all material objects are more or less fuzzy, the realization of a sharply bounded region is impossible. Never mind. The quantitative description of fuzzy relative positions by means of *counterfactual* probability distributions over mutually disjoint (sharply bounded) regions does not require that such regions be realizable by actually existing detectors.

20 Digital clocks indicate times by transitions from one reading to another, without hands. The uncertainty principle for energy and time, however, implies that such a transition cannot occur at an exact time, except in the unphysical limit of infinite mean energy (Hilgevoord, 1998).

Nothing in the quantum formalism refers to the *shape* of an object lacking internal structure. If quarks and leptons are sometimes characterized as pointlike, what is intended is that they lack (i) components and (ii) spatial extent.

And experiments? While they can produce evidence of internal structure, they cannot produce evidence of the absence of internal structure, let alone evidence of a pointlike form (inasmuch as this would be evidence of the absence of internal structure). The notion that an object without internal structure has a pointlike form — or any other form for that matter — is therefore unwarranted on both theoretical and experimental grounds.[21] In addition, it explains nothing. In particular, it does not explain why a composite object — be it a nucleon, a molecule, or a galaxy — has the shape that it does, for all empirically accessible forms are fully accounted for by the relative positions of their material constituents.

All one could possibly gain from the notion that a structureless particle has a form, is the illusion that quarks and such can be visualized (if we allow that a point can be visualized). What good does that do, considering that the smallest things consisting of quarks and electrons — namely, atoms — can *not* be visualized? (The probability distributions rendered in Figure 3, rather than being *images* of atomic hydrogen, convey information that is abstract and *counterfactual*.) It is the bigger things, starting with molecules, that have visualizable aspects, not the "smaller" ones, which make up atoms. Instead of contributing to our understanding of empirically accessible forms, the notion that a structureless particle is a pointlike object encumbers our efforts to understand the quantum world with a type of form whose existence is completely unverifiable, which is explanatorily completely useless, and which differs radically from all empirically accessible forms, inasmuch as these are sets of spatial relations.

There is, on the contrary, much to be gained by thinking of fundamental particles as formless objects. For one thing, we are then in a position to understand the coming into being of form, both in the wider sense of a set of internal relative positions and in the narrower sense of a form that can be visualized "as it is." If an object without internal spatial relations is formless, then every material form resolves itself into a set of internal spatial relations,[22] and forms (in the wider sense) come into existence through aggregation — the formation of composites. Forms in the wider sense cannot be visualized: a set of fuzzy internal spatial relations is a multidimensional construct that can only be abstractly grasped, in terms of counterfactual probability assignments. The smallest structure that can be visualized consists of the mean relative positions of a molecule's constituent nuclei — the sticks of the chemist's balls-and-sticks models. What makes this structure visualizable is the fact that the fuzziness of the relative positions of its constituents (as measured, for example, by the standard deviations of the corresponding

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21 In order to leave a visible trace (a string of bubbles in a bubble chamber, a trail of droplets in a cloud chamber, or suchlike) an electron does not need a shape; it only needs to be *there*. In fact, it is there *because* of the bubbles or droplets that indicate its whereabouts.

22 If you want to be poetic, you may say that space — the totality of existing spatial relations — is the form of the world.

probability distributions) is generally small compared to the positions themselves (as given by their mean values).[23]

For another thing, the recognition that fundamental particles are formless objects leads to a unified conception of matter and space that is elegant and economical by any standard. According to it, space is the totality of existing spatial relations,[24] while matter is the corresponding multitude of relata (Mohrhoff, 2002ab, 2005). Since there are neither relations without relata nor relata without relations, matter and space imply each other.

If physical space is the totality of existing spatial relations,[25] then all that space contains — in the proper, set-theoretic sense of "containment" — is spatial relations. It does *not* contain the corresponding relata. The ultimate constituents of matter do *not* exist in space.[26] Space contains the forms of all things that have forms — for each existing form is a subset of the set of all existing spatial relations — but it does not contain the formless constituents of matter. Instead, space exists "between" them: it is the "web" spun by their spatial relations.

But isn't this "web" located in a continuous, 3-dimensional expanse? And isn't space this continuous expanse, rather than that "web" of relations? Observe, to begin with, that spatial extension is a quality. If we subtract it from a distance, what remains is a mere number. The question therefore is, should we attribute this quality to a substance — a self-existent expanse in which spatial relations are embedded, and to which they owe their quality of spatial extension — or should we attribute it directly to each spatial relation, without the mediation of a self-existent expanse?

If we opt for the substantival conception of space — a self-existent expanse — then we must conceive of it as intrinsically undifferentiated, devoid of parts. Because the reality of spatial distinctions is relative and contingent, spatial distinctions cannot be intrinsic to space. Another look at Figure 3 helps illustrate this point. If we were to think of the expanse containing such a "cloud" as partitioned into disjoint regions, then the boundaries between these regions would divide the fuzzy relative position represented by the cloud. But it doesn't make sense to divide a position. One can break up a composite ob-

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23 There are interesting exceptions. If a part of a molecule is free to rotate relative to the rest of the molecule, its orientation is distributed over the entire range of the corresponding angular coordinate. And if a molecule can "tunnel" from one configuration to another, then its ground state is a superposition of both configurations. The standard example is ammonia (NH_3), in whose ground state the N is both above and below the plane containing the H's, in the same sense in which an electron goes through both L and R.

24 It has been claimed that relationism — the doctrine that space and time are a family of spatial and temporal relations holding among the material constituents of the universe — is untenable, inasmuch as it fails to accommodate inertial effects. See (Dieks, 2001ab) for a refutation of this claim.

25 These include not only the fuzzy relative positions of particles but also the fuzzy relative orientations of particles with spin.

26 Since the concept of a geometrical point presupposes space, the notion that a fundamental particle is pointlike implies that it "exists" or is "contained" in space. Nothing of the sort is implied if the ultimate constituents of matter are formless.

ject into its components, each having a position, but one cannot divide a position into parts each having a position. If the position of an object appears to be spread out over different “parts of space,” this just means that these parts — or the distinctions we make between them — do not exist as far as that object is concerned.

There are thus two reasons to prefer the relational conception of space. For one, postulating a substantial expanse and attributing to it the quality of spatial extension contravenes Occam’s razor (“entities should not be multiplied beyond necessity”). For another, whereas being both extended and devoid of parts is a rather paradoxical combination of properties for any substance, a fuzzy spatial relation is by nature both extended and without parts.

8 The Top-Down Structure of the Physical World

In a companion essay (Mohrhoff, 2007), I discuss another implication of the manner in which QM assigns probabilities to measurement outcomes: considered in themselves (apart from their relations) all fundamental particles are identical in the strong sense of *numerical* identity. All that can be said about an existing fundamental particle, considered in itself, is that it exists. If we give the name “pure existence” to that which every existing fundamental particle intrinsically is — the one substance that constitutes every existing material object — then we are in a position to formulate what is surely the most concise creation saga ever told: by the simple device of entering into spatial relations with itself, pure existence creates, or realizes, or takes on the aspect of both matter and space, for while space is the totality of existing spatial relations, matter is the corresponding apparent multitude of relata — *apparent* because the relations are *self-relations.*

For reasons to be explored in what follows, we attempt to build reality “from the bottom up,” either on an intrinsically and completely differentiated space or space-time, out of locally instantiated physical properties,[27] or by aggregation, out of a multitude of individual substances. QM tells us that neither attempt will succeed. Reality is built “from the top down,” by a self-differentiation of pure existence that does not “bottom out.” If we go on dividing a material object, its so-called “constituents” lose their individuality, and if we conceptually partition the physical world into smaller and smaller regions, we reach a point where the distinctions we make between the regions no longer correspond to anything in the physical world. Our spatial and substantial distinctions are warranted by property-indicating events, and these do not license an absolute and unlimited objectification of such distinctions.

27 “[A]ll there is to the world is a vast mosaic of local matters of particular fact, just one little thing and then another. . . We have geometry: a system of external relations of spatiotemporal distance between points. . . And at those points we have local qualities: perfectly natural intrinsic properties which need nothing bigger than a point at which to be instantiated. . . And that is all. . . All else supervenes on that.” (Lewis, 1986, p. X)

9 A Tale of Two Worlds

So much for the structure of the quantum world, as revealed by the testable aspects of QM. We now turn to exploring the structure of the phenomenal world.

I think it is safe to say that the following idea appears self-evident to anyone uninitiated into the mysteries of the quantum world: the parts of a material object (including the material world as a whole) are defined by the parts of the space it "occupies," and the parts of space are defined by delimiting surfaces (boundaries). Because it says, in effect, that the synchronic multiplicity of the world rests on surfaces that carve up space much as cookie cutters carve up rolled-out pastry, I have dubbed this idea "cookie cutter paradigm" (CCP) (Mohrhoff, 2001a).

The CCP is "hard-wired": the way in which the brain processes visual information guarantees that the result — the visual aspect of the phenomenal world — is a world of objects whose shapes are bounding surfaces. As there are excellent books (e.g., Hoffman, 1998; Enns, 2004) that give detailed accounts of the manner in which this world is constructed on the basis of surprisingly sparse clues from "out there" (Velmans, 2000; Durgin, 2002), the following outline must suffice.

The constructions of vision are based on a neural analysis of the visual field (the optical images falling on the retinas in both eyes) that capitalizes on contrast information. Data arriving from homogeneously colored and evenly lit regions of the visual field do not make it into conscious awareness. The corresponding regions of the phenomenal world are *filled in* (much like children's coloring books) on the basis of *contrast information* that is derived from *boundaries* in the visual field.

The extraction of discontinuities from the visual field (discontinuous changes in color and/or brightness in both the spatial and the temporal domain) begins in the retina itself (Roska and Werblin, 2001). Further downstream, in the primary visual cortex (V1), most cells are orientation selective (in the macaque monkey about seventy to eighty percent); the rest have center-surround receptive fields and are color selective.[28] Ten to twenty percent of the orientation selective cells are end-stopped, responding to short but not long line or edge stimuli. In visual area 2 (V2), at least half of the orientation selective cells are end-stopped (Livingstone and Hubel, 1988; Hubel, 1995, p. 86). It is therefore eminently plausible that the construction of the visual world is based on line segments and involves a two-step synthesis: first line segments are integrated into 3D-outlines, then these are supplemented with covering surfaces much like the wire frames of CAD software.

28 Orientation selective neurons respond best to lines of a particular orientation — bright lines on a dark background, dark lines on a bright background, or boundaries between areas of different color and/or brightness. The receptive field of a neuron is the retinal area from which input is received. A center-surround receptive field is divided into a small central region and a larger surrounding region; some neurons with such receptive fields are excited (their firing rate is increased) by illumination of the center and inhibited (their firing rate is decreased) by illumination of the surround; others are inhibited from the center and excited from the surround (Hubel and Wiesel, 1979).

If the shapes of phenomenal objects are bounding surfaces, and if what divides the phenomenal world into parts is delimiting surfaces, it is only natural that our conceptions of the physical world should conform to the CCP — and that we should be perplexed by Nature's refusal to follow suit. Let us look at some of the paradigm's implications and see how they lead us down the garden path.

In a world whose synchronic multiplicity rests on surfaces, spatial extension exists in advance of multiplicity, for only what is extended can be cut up by the three-dimensional equivalents of cookie cutters. If, in addition, the parts of material objects are defined by the parts of space, then the parts of space exist in advance of the parts of material objects. This is how the CCP leads us to think of space as a pre-existent and intrinsically divided expanse.[29]

But if this is how we think, then we cannot conceive of fuzzy positions. If parts are defined by geometrical boundaries, the relative positions of parts are as sharply defined as their boundaries, and there isn't anything fuzzy about the way geometrical boundaries are defined. In an intrinsically and completely differentiated spatial expanse, all conceivable parts exist in an absolute sense, and are therefore real for all material objects. This means that for every material object O and for every conceivable region V, the proposition "O is in V" possesses a truth value at all times. (In the case of a composite object, "O" stands for the object's center of mass.) All possessed positions are sharp. This is why the two-slit experiment with electrons "is impossible, absolutely impossible, to explain in any classical way" (Feynman et al., 1965, Sec. 1–1).

If we combine the pre-existence of a spatial expanse with the theoretically as well as empirically supported existence of particles lacking spatial extent, we are led on to the notion that such particles are pointlike. An object lacking spatial extent may be either pointlike or formless, but if it is situated in a pre-existent expanse, then it has a form. If in addition the expanse is intrinsically differentiated, then it stands to reason that it is differentiated "all the way down." But if it is differentiated at all scales of length, then the form of a particle lacking spatial extent can only be that of a geometrical point. This is how we come to think of fundamental particles as pointlike objects.

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29 The statement that the parts of space are defined by delimiting surfaces, has two possible readings. To thinkers from Aristotle to Kant and Gauss it appeared self-evident that space wasn't the kind of thing that can be composed of parts. (If space were a composite object, one would have to address the absurd question of how its parts are held together.) They considered space as an expanse that makes it possible to divide *material* objects — in accordance with the CCP, needless to say. The "parts of space" exist as possibilities, some of which are realized, in geometry through the explicit construction of delimiting surfaces, in the physical world as material surfaces (von Weizsäcker, 1980). "Space is essentially one," Kant (1781, p. 25) wrote, "the manifold in it... arises entirely from the introduction of limits." These thinkers reflected on the expanse of space as it is "given" to us in perception and imagination. If instead we think about space along realist lines, as an aspect of a self-existent world, and if we do this in conformity with the CCP, we are led to postulate a self-existent spatial expanse. And since the CCP defines the parts of material objects by the parts of space, we are led to think of the parts of space as intrinsic to this pre-existent expanse.

And there are more ways in which our neurobiology tends to mislead us. Although we readily agree that red, round, or a smile cannot exist without a red or round object or without a smiling face, we just as readily believe that positions can exist without being properties of material objects. We are prepared to think of material objects as substances, and we are not prepared to think of the properties of material objects as substances — except for one: we tend to think of positions as if they existed by themselves, without being possessed. The reasons for these disparate attitudes reside in the neurobiology of perception, as the following will show.

The visual cortex is teeming with feature maps. A feature map is a layer of the cerebral cortex in which cells map a particular phenomenal variable (such as hue, brightness, shape, motion, or texture) in such a way that adjacent cells generally correspond to adjacent locations in the visual field. In the macaque monkey as many as 32 distinct feature maps have been identified (Clark, 2000). Every phenomenal variable has a separate map (and usually not just one but several maps at different levels within the neuroanatomical hierarchy) except location, which is present in all maps. If there is a green box here and a red ball there, "green here" and "red there" are signaled by neurons from one feature map, and "boxy here" and "round there" are signaled by neurons from another feature map. "Here" and "there" are present in both maps, and this is how we know that green goes with boxy and red goes with round. Position is the integrating factor.[30] In the brain, and consequently in the phenomenal world, positions pre-exist — in the brain at a scale defined by the resolving power of neurons, in the phenomenal world at visually accessible scales. They exist in advance of *phenomenal* objects, and this is another reason why we tend to assume that they also exist in advance of *physical* objects, not only at the scale of neurons or at visually accessible scales, but also at the scales of atoms and subatomic particles. The transition from visually accessible scales to subatomic scales is an unwarranted extrapolation, but if one postulates a pre-existent spatial expanse that is intrinsically differentiated at some scales, then it is hard to see why it is not intrinsically differentiated at all scales.

Here is another reason why we tend to think of positions as substances: the role that position plays in perception is analogous to the role that substance plays in conception. Among the ideas that philosophers have associated with the word "substance," the following is relevant here: while a property is that in the world which corresponds to the predicate in a sentence composed of a subject and a predicate, a substance is that in the world which corresponds to the subject. It objectifies the manner in which a conjunction

30 Features present in the same place get integrated into a single object, while features present in different places get integrated into different objects (or different parts of the same object). This is why we are convinced by default that one and the same object cannot be in different places, and that different objects cannot be in the same place. It is also why we are baffled by the apparent ability of a single electron to be simultaneously in different places, and by the ability of two or more particles to be in possession of exactly the same (fuzzy) position. (Helium illustrates this nicely. In the ground state of a helium atom, the positions of the two electrons relative to the nucleus are exactly identical. And in the superfluid state of liquid helium, the positions of the helium atoms are exactly identical relative to the bottle that contains them.)

of predicative sentences with the same subject term bundles predicates. While substance thus serves as the “conceptual glue” that binds an object’s properties, position serves as the “perceptual glue” that binds an object’s phenomenal features.

The world according to QM	The world according to the CCP
Synchronic multiplicity rests on spatial relations.	Synchronic multiplicity rests on delimiting surfaces.
Space is the totality of existing spatial relations.	Space is a pre-existent expanse that is intrinsically differentiated “all the way down.”
The only existing positions are the relative positions of material objects.	Positions exist by themselves, whether or not they are possessed.
All existing (= possessed) positions are fuzzy.	All existing positions are sharp.
The reality of spatial distinctions is relative and contingent.	The reality of spatial distinctions is absolute.
Spatial extension is a quality of spatial relations.	The spatial quality of spatial relations is derivative. Spatial extension is primarily the quality of a pre-existent expanse.
A particle without internal structure is a formless object.	A particle without internal structure is a pointlike object.
The form of an object with spatial extent consists of the object’s internal spatial relations.	The form of an object with spatial extent is a bounding surface.
The spatiotemporal differentiation of the world is incomplete.	The spatiotemporal differentiation of the world is complete.
The world is structured from the top-down.	The world is built from the bottom up, either on an intrinsically and completely differentiated spatial or spatiotemporal expanse or out of a multitude of “ultimate constituents.”

The above table contrasts the salient features of the quantum world with the corresponding features of a world constructed along the lines laid down by the CCP. Seasoned quantum mechanicians may smile (or scoff) at the naivety of some of the items in the right column, some of which are mutually inconsistent, such as the combination of pointlike ultimate constituents with the notion that the form of an object with spatial extent is a bounding surface. Nevertheless, this table has proved itself very useful in explaining to undergraduates and even high school students (grades 11–12) why making sense of the quantum world is so hard.

As long as some of the items in the right column remain part of our theoretical modeling of the quantum world — in particular the notions that space is an intrinsically and completely differentiated, pre-existent expanse, that the reality of spatial distinctions is absolute, and that a particle without internal structure is a pointlike object — it seems safe to say that our attempts to beat sense into QM are doomed. That some of these notions are indeed entertained by all major interpretational schemes will become evident as we proceed.

10 Pseudo-problems and Gratuitous Solutions

In this section we will examine the insidious influence of the CCP on our attempts to make sense of the quantum world.

At the heart of the quantum formalism is the amplitude $\langle x_f, t_f | x_i, t_i \rangle$ associated with the conditional probability of finding a particle at the position x_f by way of a measurement performed at the time t_f,[31] the condition being that the particle was last detected at x_i by way of a measurement performed at t_i.[32] This amplitude (a. k. a. "propagator") allows us to introduce the "wave function" $\psi(x,t)$ via

$$\psi(x_f, t_f) = \int dx_i \langle x_f, t_f | x_i, t_i \rangle \psi(x_i, t_i).$$

For various reasons the wave function is widely regarded as the primary concept and the propagator as derivative. One reason is the historical precedence of Schrödinger's "wave mechanics" over Feynman's superior propagator-based formulations of QM. Another reason is Kolmogorov's (1950) definition of conditional probabilities in terms of absolute probabilities, which suggests that the latter have primacy over the former. If absolute rather than conditional probabilities are basic, then the obvious correspondence of wave functions to absolute probabilities and of propagators to conditional probabilities strongly suggests that wave functions have primacy over propagators. In reality, QM has as little to do with absolute probabilities as it has with Bohmian trajectories.[33] Every quantum-mechanical probability is conditional on the actual measurement outcome (or outcomes) on the basis of which it is assigned to a possible measurement outcome.[34]

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31 What is meant by this common but potentially misleading phraseology is the probability of detecting the particle in a region $\mathcal{V}$ containing x_f, divided by the volume V of $\mathcal{V}$, in the limit $V \to 0$.

32 If we are dealing with a system consisting of a fixed number n of particles, x stands for a set of $3n$ coordinates, and $\psi(x,t)$ encapsulates the probabilities of the possible outcomes of any measurement that may be performed on the system at the time t. In relativistic QM, the number of particles is variable, and $\psi(x,t)$ — now technically an operator and called a "quantum field" — defines a joint probability distribution over (i) particle sets and (ii) outcomes of measurements performed on any given particle set.

33 An axiomatic alternative to Kolmogorov's formulation of probability theory was developed by Rényi (1955). Since Rényi's (1970, Chap. 2) formulation is based entirely on conditional probabilities, it provides a mathematical context for thinking about quantum-mechanical probabilities that is more appropriate than Kolmogorov's formulation (Primas, 2003).

34 The probability distributions in Figure 3, for example, are determined by the outcomes of measurements of the atom's energy and the magnitude and vertical component of its angular momentum.

There is no such thing as an "unprepared" wave function.[35]

Classical physics can be neatly divided into *kinematics*, which concerns the description of physical systems at any one time, and *dynamics*, which concerns the evolution of physical systems from earlier to later times. This *evolutionary paradigm* rests on the more or less tacit assumption that physical time is intrinsically and completely differentiated, which in a relativistic world implies that space is so, too. Since the quantum-mechanical probability assignments imply that physical space and physical time are *neither* intrinsically *nor* completely differentiated, it is clear that QM and the evolutionary paradigm are mutually inconsistent. In spite of this, ever since the von Neumann's influential *Foundations* (1932), textbooks list versions of the following statements among the axioms of QM:

(X) Between measurements, wave functions (or quantum states) evolve according to unitary transformations (and thus continuously and predictably).

(Y) By way of measurement, wave functions (or quantum states) evolve as stipulated by the projection postulate (and thus in general discontinuously and unpredictably).[36]

While the real trouble with these claims is that they postulate two modes of evolution rather than *none*, virtually everybody agrees that the trouble with QM is the postulation of two modes of evolution rather than *one*.[37] While unitary evolution is "normal" and therefore in no need of explanation, the second, "anomalous" mode of evolution gives rise to the mother of all quantum-mechanical pseudo-problems: how to explain (away) the unpredictable "collapses" of wave functions during measurements?

Stripped of the notion that quantum states evolve, (X) and (Y) state the obvious. An algorithm for assigning probabilities to possible measurement outcomes on the basis of actual measurement outcomes has two perfectly normal dependences. It depends continuously on the time of the measurement: if you change the time of measurement by a small amount, the probabilities assigned to the possible outcomes change by small amounts. And it depends discontinuously on the outcomes that constitute the assignment basis: if you take into account an outcome that was not previously taken into account, the assignment basis changes unpredictably as a matter of course, and so in general do the assigned probabilities.

The wave function's dependence on time cannot then be the time dependence of

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35 If probabilities are assigned to possible later measurement outcomes on the basis of earlier actual outcomes, then the wave function used in calculating these probabilities is said to be "prepared" (by the earlier outcomes).

36 A more recent version (Fuchs, 2002) goes like this: (X) Between measurements, quantum states evolve according to trace-preserving completely positive linear maps (and thus continuously and predictably). (Y) By way of measurement, quantum states evolve (up to normalization) via outcome-dependent completely positive linear maps (and thus in general discontinuously and unpredictably).

37 There are notable exceptions, e.g., "there is no interpolating wave function giving the 'state of the system' between measurements" (Peres, 1984).

something that obtains at every instant (a state of affairs of some sort) and evolves. Nor is $\psi(x,t)$ something that exists at x. After all, the probability of detecting a particle at a particular location at a particular time is not something that exists at a particular location or obtains at a particular time. The t in $\psi(x,t)$ refers to the time of a *measurement.* Quantum-mechanical probability assignments are made with the implicit assumption that a measurement with a given set of possible outcomes is (successfully) made at a given time.[38] Out of relation to measurements, t is undefined, and so is ψ.

It is odd that the ontological and/or epistemological status of the wave function has been the focus of a lively controversy for almost a century, whereas the ontological status of the coordinate points and instants on which ψ functionally depends has hardly ever been called into question.[39] Rather, the existence of exact locations and times is taken for granted by virtually every quantum field theorist and philosopher of science.[40] Virtually every paper concerning the ontology of quantum field theory — the mathematical structure known to be in complete accord with the observational data — begins by postulating the existence of an intrinsically and completely differentiated background space-time (e.g., Halvorson and Clifton, 2002). It therefore comes as no surprise that the interpretation of QM is beset with pseudo-questions and gratuitous answers. As long as the existence of such a background space-time is assumed, it is safe to say that our attempts to beat sense into QM are doomed.[41]

11 The Real Problem and Its Solution

At this point it should be clear that the real challenge posed by QM is to understand, rather than explain away, its reliance on measurements. And it is a real challenge. The maxim that "to *be* is to be *measured*" seems to entail a vicious regress. No value is a pos-

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38 As we have seen, even counterfactual probability assignments cannot be made without reference to measurements, albeit unperformed ones.

39 Exceptions are found in the literature on quantum gravity, where it is occasionally observed that a fuzzy metric — fuzzy distances and durations — conflicts with the description of space-time as a set of "point-instants" or "events" that are sharply localized relative to each other.

40 According to philosopher of science M. L. G. Redhead (1983), "[a] field theory in physics is a theory which associates certain properties with every point of space and time."

41 Recognizing that wave functions are probability algorithms but not realizing the nature of their time dependence, many feel the need to explain how possibilities — or worse, probabilities (Treiman, 1999, p. 188) — become facts. Yet this isn't something that needs explaining. Saying in common language that a possibility has become a fact is the same as saying that something that is possible — something that *can* be a fact — actually *is* a fact. The non-problem of how something that can be a fact can be a fact becomes a problem only if the common-language "existence" of a possibility is construed as a lesser kind of existence — some mystical matrix of "propensities" (Popper, 1982) or "potentialities" (Heisenberg, 1958, Chap. 3; Shimony, 1989), which transform into the genuine article (non-existence proper or existence proper) by way of measurement. It is the sort of pseudo-problem that is bound to arise if one misconstrues a probability algorithm as an evolving state of affairs (Mohrhoff, 2002a).

sessed value unless it is indicated, and a pointer position is no exception; it has a value only because, and only to the extent that, its value is indicated by other "pointer positions." How, then, can a detector (in the broadest sense of the word) realize a region R (or the distinction between "inside R" and "outside R")? If the buck is to stop somewhere, some positions must be different.[42]

And they are. The possibility of obtaining evidence of the departure of an object O from its classically predictable position (given all relevant earlier position-indicating events) calls for detectors whose position probability distributions are narrower than O's — detectors that can probe the region over which O's fuzzy position extends. Such detectors do not exist for all objects. Some objects have the sharpest positions in existence. For these objects, the probability of obtaining such evidence is necessarily very low. Hence *among* these objects there are many of which the following is true: every one of their indicated positions is consistent with (i) every prediction that is based on their previous indicated positions and (ii) a classical law of motion. Such objects deserve to be called *macroscopic.* To enable a macroscopic object to indicate an unpredictable value, one exception has to be made: its position may change unpredictably if and when it serves to indicate such a value.

For various reasonable definitions of "macroscopic" it has been shown that the probability of finding a macroscopic object where classically it could not be, is extremely low.[43] This guarantees the existence of macroscopic objects according to our stricter definition. (Our definition does not require that the probability of finding a macroscopic object where classically it could not be is strictly zero. What it requires is that there be no position-indicating event that is inconsistent with predictions based on a classical law of motion and earlier position-indicating events.)

To terminate that apparent vicious regress, we must be allowed to look upon the positions of macroscopic objects — macroscopic positions, for short — as intrinsic, as self-indicating, or as real *per se*. To see that this is indeed legitimate, recall that the extrinsic nature of the values of physical variables is a consequence of their fuzziness. Macroscopic positions too are are fuzzy, but not manifestly so, for their fuzziness never evinces it-

42 According to some measurement theorists, the difference consists in their being perceived or known. For an analysis of this gratuitous maneuver see (Mohrhoff, 2002ac).

43 Detailed studies of a large class of specific models, carried out over the past two decades, have demonstrated that the reduced density operators associated with sufficiently large and/or massive systems, obtained by partial tracing over realistic environments, become very nearly diagonal with respect to a privileged basis in very short times, and that they stay that way for very long times (Zurek, 2003; Blanchard et al., 2000; Joos et al., 2003). In such systems, environment-induced *decoherence* leads to *einselection* (environment-induced superselection) of a "pointer basis." The special role played by positions can be traced to the fact that all known interaction Hamiltonians are local — they contain δ functions of relative positions. Because of this, the spreading of wave packets ordained by the uncertainty relations (and sped up by non-linear dynamics) is counterbalanced by an ongoing localization relative to the environment. The result is a compromise between localization in position space and localization in momentum space. In the appropriate macroscopic limit the hallmark of classicality — localization in phase space — obtains.

self through outcomes that are inconsistent with predictions that are based on earlier outcomes and a classical law of motion. They are fuzzy only in relation to an imaginary background that is more differentiated spacewise than is the actual world. Because the region over which such a position is "smeared out" is never probed, macroscopic objects follow trajectories that are only counterfactually fuzzy. Therefore we have every right to treat them as intrinsic, not merely for all *practical* purposes but for all *quantitative* ones.

More can be established. For whereas we may think of an individual macroscopic position as intrinsic only for all quantitative purposes, nothing stands in the way of attributing to the *entire* system of macroscopic positions an *independent* reality. Nothing prevents us from looking upon the entire system of possessed relative positions and their relata — the *macroworld*, for short — as self-contained.

A fundamental physical theory concerned with nothing but statistical correlations between property- or value-indicating events presupposes the occurrence of such events. How can such a theory can be complete, i.e., how can it at the same time *encompass* these events? The answer calls for a judicious choice on our part: which substructure of the complete theoretical structure of QM corresponds to what exists? Independent reality can be consistently attributed neither to an intrinsically divided space-time nor to a multitude of microscopic constituents nor to an evolving quantum state but only to the macroworld. This is a substructure in two senses: it is part of the complete theoretical structure of QM, and containing as it does the value-indicating events presupposed by QM (as unpredictable transitions in the values of macroscopic positions) it is also the self-existent foundation on which all indicated properties and values supervene.

12 Farewell to Causality

"There are no 'wheels and gears' beneath this analysis of Nature," Feynman (1985) observed in his beautiful little book *QED: The Strange Theory of Light and Matter*. Indeed, nothing in the quantum formalism gives us a clue as to "how Nature does it." One of the reasons why physicists feel let down by QM is the misconception that it has once been otherwise — that the *classical* dynamical laws did describe physical processes by which "nature does it."

Take classical electrodynamics. It allows us to calculate the effects that charges have on charges. The calculation involves two steps. (i) Given the distribution and motion of charges, we calculate six functions, the components of the so-called electromagnetic field (a tensor depending on position and time). (ii) Given these six functions, we calculate the effect that those charges have on any other charge. And that's it. The rest is embroidery, including the belief that the unobservable electromagnetic field[44] is a physical entity in its own right, that it is locally generated by charges, that it locally acts on charges, that it mediates interactions by locally acting on itself, and that this *explains*

44 All that can be observed in this context is (i) the accelerations that charges undergo and (ii) the distribution and motion of charges responsible for the accelerations.

how charges act on charges.[45] All we have in the imaginary world of classical physics is correlations between events. Being governed by deterministic laws, these correlations can be thought of as causal relations. What we do not have is any idea of how — by what mechanism or process — causes produce their effects.

This conclusion can also be reached by a different route. In the quantum world, all we have is rules for calculating probabilities. In the so-called "classical limit," in which the fuzziness that fluffs out matter disappears, the quantum-mechanical probability algorithms become trivial, in the sense that the only probabilities they then assign are the trivial probabilities 0 and 1 (Mohrhoff, 2002bd). This permits us to think of the properties or values to which probability 1 is assigned as constituting an actual state of affairs. If we do so, the quantum-mechanical probability algorithms degenerate into rules for calculating the effects that material objects have on material objects. They do not transform into mechanisms or processes by which material objects act on material objects.

And there is more. Encapsulating correlations between measurement outcomes, the laws of QM cannot account for the *existence* of measurement outcomes. The probability that a variable Q has the value q is the product of two probabilities — the probability with which any one of the possible values of Q is indicated (no matter which), and the probability that the indicated value is q given that a value is indicated. QM is exclusively concerned with probabilities of the latter kind. It is therefore beyond the scope of QM to formulate sufficient conditions for the occurrence of property- or value-indicating events. If QM is indeed the fundamental theoretical framework that most physicists believe it is, this means that such events are *uncaused* (Mohrhoff, 2000, 2002c). This should not be confused with the fact that QM cannot in general predict the outcome of a successful measurement. Not only there isn't anything that necessitates the occurrence of this *rather than* that outcome, but also there isn't anything that necessitates the occurrence of *any* outcome.

Thus it should not come as a surprise that the quantum-mechanical literature is replete with physical scenarios that patently defy causal accounts (e.g., Laloë, 2001, Greenstein and Zajonc, 1997). Here is one such scenario (Greenberger et al., 1989). QM allows us — in theory, and probably soon enough in the laboratory — to entangle[46] the spins of three particles in such a way that whenever the x components of the three spins are measured, their product comes out negative, and whenever the x component of any one spin and the y components of the two other spins are measured, the product of the measured components comes out positive. To see what this entails, consider the following game (Vaidman, 1999).

45 With the notable exception of Roger Boscovich, a Croatian physicist and philosopher who flourished in the 18th Century, nobody seems to have noticed that local action is as unintelligible as the ability of material objects to act where they are not. Why do we stop worrying once we have transmuted the mystery of action at a distance into the mystery of local action?

46 Saying that two physical systems are "entangled" is the same as saying that the possible outcomes of certain measurements performed on them are correlated.

Andy, Bob, and Charles play as a team. Each of them is asked either of two questions: "What is the value of x?" or "What is the value of y?" Each may answer with either "+1" or "–1." The rules of the game are such that either only x questions are asked or one x question and two y questions are asked. The three players win if the product of their answers is –1 in case only x questions are asked, and if the product is +1 in case y questions are asked. Otherwise they lose. The questioning takes place in three remote locations, so that it is impossible for the players to communicate with each other. Before being taken to these locations, however, they may work out a strategy. Is there an infallible strategy?

Here is a strategy that does *not* work: the players decide beforehand which answers they will give. Let X_A and Y_A stand for Andy's pre-agreed answers, X_B and Y_B for Bob's, and X_C and Y_C for Charles's. These six numbers must satisfy the following equations if the three players are to win every time:

$$X_A X_B X_C = -1, \quad X_A Y_B Y_C = 1, \quad Y_A X_B Y_C = 1, \quad Y_A Y_B X_C = 1.$$

The product of the left-hand sides of the last three equations equals $X_A X_B X_C$ (squares of Y's drop out because they equal +1), while the product of their right-hand sides equals +1, implying that $X_A X_B X_C$=+1, in contradiction to the first equation. Evidently, the four equations cannot be simultaneously satisfied.

And yet there is a strategy that always works. Each player takes with him one of the three particles whose spins are entangled as described above. Whoever is asked the x question measures the x component of the spin of his particle and answers "+1" or "–1" according as the result is positive or negative; whoever is asked the y question measures the y component of the spin of his particle and answers likewise.

The inescapable conclusion is that these measurements do not simply reveal pre-existent values. And since there is nothing special about this particular setup (and because there are many scenarios that lead to the same conclusion, if less directly) this conclusion bears generalization: instead of revealing pre-existent properties or values, measurements *create* their outcomes.

In this particular case, the outcomes are created in such a way that the result of the measurement performed on any one particle is determined by the results of the measurements performed on the two other particles: if either the x components or the y components of two spins are measured, the outcome of a measurement of the x component of the third spin can be predicted with certainty, and if one x component and one y component are measured, the outcome of a measurement of the y component of the third spin can be predicted with certainty. How is this possible given

- that the values of the spin components are created as and when they are measured,
- that the relative times of the measurements are irrelevant, and
- that the three particles can in principle be thousands of miles apart?

How does the third spin or apparatus "know" about the outcomes of the two other spin measurements? What mechanism correlates the outcomes? You understand this as much as anybody else. Einstein spoke of "spooky actions at a distance" (*spukhafte Fernwirkungen*) and hoped they would eventually go away. A decade after Einstein's death this hope was dashed by John Bell (1964, 1966). Spooky actions at a distance are here to stay. What is so unsettling is not that we don't know how to explain them, nor even that the quantum-mechanical correlation laws leave no room for causal embroidery, inasmuch as the "classical" sleight of hand — the transmogrification of mathematical symbols or algorithms into physical entities or processes — no longer works. What is so unsettling is that these correlations do not seem possible at all. We seem to have exhausted all possibilities of explaining them.

Given the manner in which the phenomenal world is constructed by our minds an/or brains, we naturally share Einstein's belief that "things claim an existence independent of one another" whenever they "lie in different parts of space" (Einstein, 1948). It is ironic that Einstein based his belief in the mutual independence of objects situated in different parts of space on the demand that these objects be *independent* of the perceiving subject, for it is precisely the illegitimate projection of the structure of the *phenomenal* world into the physical world that underlies this belief. It is because the visual world is constructed in conformity with the CCP that we tend to think of space as a pre-existent and intrinsically differentiated expanse, in which objects are separated by "empty space."

Fact is that the three spins, which may be light years apart, are not independent of one another. Fiction is that they lie in different parts of space. Space isn't something that has parts. Nor is there such a thing as empty space, not because space is "filled with vacuum fluctuations" as the popular literature has it, but because in the physical world (as against the phenomenal world) there are no unoccupied locations or unpossessed positions. Where there is nothing (no thing) there is no "there." If we add to this that all existing relations are self-relations of pure existence, we find that there is neither a structural nor a substantial basis on which physical things could "claim an existence independent of one another."

Physics concerns correlations. Classical physics concerns deterministic correlations, which admit of causal stories, while quantum physics concerns statistical correlations, which don't. The reason why causal concepts are nevertheless useful is that the vast majority of our stories supervene on the behavior of macroscopic positions. Causal stories work for macroscopic objects because every measured macroscopic position is consistent with a classical law of motion (unless it serves as a "pointer").

13 Physics and Presentism

We are accustomed to the idea that the redness of a ripe tomato exists in our minds, rather than in the physical world. We find it incomparably more difficult to accept that the same is true of the experiential now: it has no counterpart in the physical world. There simply is no objective way to characterize the present. And since the past and the future are defined relative to the present, they too cannot be defined in physical terms. The temporal modes past, present, and future can be characterized only by how they relate to us as conscious subjects: through memory, through the present-tense immediacy of experience, or through anticipation. In the world that is accessible to the methods of the physical sciences, we may qualify events or states of affairs as past, present, or future *relative* to other events or states of affairs, but we cannot speak of *the* past, *the* present, or *the* future. The proper view of physical reality therefore is not only what Nagel (1986) has called "the view from nowhere" (the physical world does not contain a preferred position corresponding to the spatial location whence I survey it); it is also what Price (1996) has called "the view from nowhen": the physical world does not contain a preferred time corresponding to the particular moment (the present) at which I experience it.[47] The idea that some things exist not yet and others exist no longer is as true (psychologically speaking) and as false (physically speaking) as the idea that a ripe tomato is red.

If we conceive of temporal or spatiotemporal relations, we conceive of the corresponding relata simultaneously — they exist at the same time *in our minds* — even though in the physical world they happen or obtain at different times. Since we cannot help it, that has to be OK. But it is definitely not OK if we sneak into our simultaneous mental picture of a spatiotemporal whole anything that advances across this spatiotemporal whole. We cannot mentally represent a spatiotemporal whole as a simultaneous spatial whole and then imagine this simultaneous spatial whole as persisting in time and the present as advancing through it, as some process philosophers appear to do (Whitehead, 1978; Hartshorne, 1991; Griffin, 1998). There is only one time, the fourth dimension of the spatiotemporal whole. There is not another time in which this spatiotemporal whole persists as a spatial whole and in which the present advances. If the experiential now is anywhere in the spatiotemporal whole, it is trivially and vacuously everywhere — or, rather, everywhen.

In a world that has no room for an advancing now, time does not "flow" or "pass." To philosophers, the perplexities and absurdities entailed by the notion of an advancing objective present or a flowing objective time are well-known.[48] To physicists, the unreality of a temporally unextended yet persistent and continually changing present was brought home by the discovery of the relativity of simultaneity. For any two events A,B there exist two reference frames F_A and F_B and a third event C such that C is simultaneous with A in F_A and simultaneous with B in F_B. This "simultaneity by proxy" of A with B compels us to conceive of all parts of the spatiotemporal whole as coexistent and as equally real. It is Nature's refutation of presentism, the view that only the present is real, or that it is somehow "more real" than the future and the past. What is less widely recognized is that the ontological implications of QM are equally inconsistent with presentism: a world that fails to be infinitely differentiated timewise cannot be built up

47 If Nagel's phrase is taken to mean "the view without a viewer" then it implies the absence of a viewpoint in both space and time.

48 See, for instance, the illuminating entry on "time" in Audi (1995).

from a succession of instantaneous states.[49]

While our successive experience of the world's temporal aspect makes it natural for us to embrace presentism, our self-experience as agents makes it natural for us to hold that the past, being known or knowable in principle, is "fixed and settled," that the unknown and apparently unknowable future is "open," and that causality is directed from a settled past toward the open future. These notions, too, are incongruous with the physical world, inasmuch as physically the past, the present, and the future are on an equal footing. Moreover, the physical correlation laws (both the deterministic classical ones and the probabilistic quantum-mechanical ones) are time-symmetric. They allow us to retrodict as well as to predict. The quantum-mechanical ones allow us to assign posterior probabilities (on the basis of later measurement outcomes) as well as prior probabilities (on the basis of earlier outcomes) and even probabilities that depend on both earlier and later outcomes.[50]

It has been claimed (e.g., by Stapp, 2001) that the indeterminism of QM rids us of the "block universe" (Smythies, 2003) of relativistic physics, in which the future is as "fixed and settled" as the past, and that it thereby makes room for a genuine (libertarian) free will. This claim compounds two errors. For one thing, QM implies the coexistence of the spatiotemporal whole as much as the classical theory of relativity does. For another, there is no basis for claiming that the coexistence of the spatiotemporal whole precludes a genuine free will. The fact that an *already* existing future cannot depend on a libertarian free choice is beside the point, for there is no such thing as an "already existing future" — it is a contradiction in terms. Tomorrow's events happen tomorrow and not today. The coexistence of the spatiotemporal whole implied by both special relativity and QM is not a simultaneous but a tenseless or *atemporal* one. It in no way rules out that the spatiotemporal whole is to a significant extent determined by choices that are freely made (in the libertarian sense). The only thing that could preclude free choice (in any sense) is the possibility of foreknowledge: if the future were as accessible as the past, I could know my choices before I make them, and in this case I could not feel as if I made

49 Why would an evolving physical present have to be *instantaneous*? After all, the experiential now has "thickness," and an evolving physical state is, if anything, a projection of the experiential now. The reason why presentists cannot countenance a thick evolving state is that a thick physical present cannot be explained from the bottom up, the way Humphrey's (2000) "thick moment of consciousness" can be explained — by "a kind of self-resonance that effectively stretches out the present moment." There isn't another physical present that could be stretched out to create a thick *physical* present. If a thick physical presented existed, it would have to be understood from the top down, as the result of an incomplete temporal differentiation of the spatiotemporal whole, a differentiation that proceeds from the whole and peters out before reaching the infinitesimal limit. But this presupposes what presentism denies: the coexistence or equal reality of all parts of the spatiotemporal whole.

50 The latter are calculated according to the ABL rule (Aharonov et al., 1964 ; Mohrhoff, 2001b) rather than the standard Born rule, and they are extracted from a "two-state" (introduced by Aharonov and Vaidman, 1991) rather than the standard wave function or quantum state. The possibility that a quantum state can be "retropared" (by later measurements) as well as "prepared" (by earlier measurements, see Note 35) is conveniently ignored by those who attempt to transmogrify the wave function into an evolving physical/ontological state.

them of my own free will. But the future is a well-kept secret, as we all know.[51]

If we combine the figment of a causal arrow with the figment of an instantaneous state and project the result — an evolving instantaneous state — into the physical world, we arrive at the well-known folk tale according to which causal influences reach from the (no longer existent) past to the (not yet existent) future through persisting "imprints" on the present. If the past and the future are nonexistent, the past can influence the future only through the mediation of something that persists. Causal influences reach from the past into the future by being "carried through time" by something that "stays in the present." This evolving instantaneous state includes not only all presently possessed properties but also traces of everything in the past that is causally relevant to the future. In classical physics this is how we come to conceive of "fields of force" that (i) evolve in time (and therefore, in a relativistic world, according to the principle of local action) and (ii) mediate between the past and the future (and therefore, in a relativistic world, between local causes and their distant effects). In quantum physics, this is why we tend to seize on a time-dependent probability algorithm and transmogrify it into an evolving instantaneous state.

14 Quanta and Vedanta

The physical world is built from the top down, by a self-differentiation of pure existence that brings into being both space (a multitude of spatial relations) and matter (the corresponding multitude of relata). In a companion essay (Mohrhoff, 2007) I identified this pure existence with the Vedantic *brahman*, with a view to elucidating the relationship between consciousness and matter. The same identification helps understand why it is not merely futile but completely unnecessary to search for a physical mechanism or process that could explain the efficacy of fundamental physical laws.[52] In the Vedantic scheme of things (Sri Aurobindo, 1981; Phillips, 1995), the dynamic link between *brahman* and the world is an *omnipotent* conscious force (*chit-tapas*) — a force that spontaneously realizes its creative ideas. If this works in a way that is amenable to mathematical description, we need to know the reason why, and the extent to which, it does so. If it sub-

51 In a small way, the possibility of foreknowledge appears to exist. Cortical precursors of voluntary movements can be used to anticipate (Deecke et al., 1969; Libet, 1985, 1999) and preempt (Grey Walter, 1963; Glaxton, 1999) people's own conscious decisions. In addition, research by Radin (1997), Bierman and Radin (1997), Bierman (2000), and James et al. (2003) has suggested that skin conductance and other autonomic measures can act as statistical predictors of a future experience. Unlike the tenseless coexistence of the spatiotemporal whole, these data are relevant to the free-will debate.

52 Futile because no fundamental theory can be explained by a "more fundamental" theory, for a "less fundamental" theory is not fundamental at all. For materialists, this is a serious problem, hence their attempts to render the fundamental laws self-sufficient by ontologizing their mathematical ingredients. If this succeeded, it would allow them to imagine themselves "omniscient in principle," i.e., to believe that they know the furniture of the universe and the laws that govern its behavior. But it cannot succeed, for QM does not yield to the "classical" sleight of hand, the transmogrification of mathematical symbols or algorithms into physical entities or processes.

jects itself to laws, we need to know why it does so and why to this particular set of laws rather than another.[53] But there obviously is no need to account for the efficacy of an omnipotent force.

Here is how QM lends support to this scheme. According to its laws, everything is possible — i.e., every conceivable measurement outcome has a probability greater than zero — *unless* it violates a conservation law. We never have to explain why something is possible. We *only* have to explain why certain things are *not* possible. Isn't this precisely what one would expect from the self-constrained working of an omnipotent force?

From the Vedantic point of view, our thinking's all but incorrigible conformance to the CCP has deeper roots than the neurobiological findings presented in Section 9. *Brahman* relates to the world as an all-constituting substance (*sat*) and as an all-containing consciousness (*chit*). An all-containing consciousness that is at the same time an all-constituting substance is necessarily very different from the consciousness we are familiar with. Using Sri Aurobindo's (1987) terminology I shall call it as "supermind." The action of supermind is primarily qualitative and infinite and only secondarily quantitative and finite. *Brahman* relates to the world not only as its constituent and continent but also (subjectively speaking) as an infinite bliss and (objectively speaking) as an infinite quality or value (*ānanda*) experiencing and expressing itself in it. Mind, in the same terminology, is essentially the agent of the secondary, quantifying, and delimiting action. Though subordinate to the all-originating supermind, it is a cosmic principle and not just something that our brains "squirt out."

> Mind in its essence is a consciousness which measures, limits, *cuts out* forms of things from the indivisible whole and contains them as if each were a *separate integer*. Even with what exists only as obvious parts and fractions, mind establishes this fiction of its ordinary commerce that they are things with which it can deal separately and not merely as aspects of a whole. . . It is this essential characteristic of Mind which conditions the workings of all its operative powers, whether conception, perception, sensation or the dealings of creative thought. It conceives, perceives, senses things *as if rigidly cut out from a background or a mass* and employs them as fixed units. . . (Sri Aurobindo, 1987, p. 162, emphases added).

Einstein's belief that "things claim an existence independent of one another" whenever they "lie in different parts of space" gives expression to the mind's way of dealing with reality. Mind "cuts out forms of things from the indivisible whole and contains them as if each were a separate integer." If the mentally perceived and conceived separateness of things situated in different parts of space is given the status of a fundamental ontological truth, things can influence each other only by some kind of direct contact, across common boundaries. It is to this naive idea that physicists give the grand name "principle of local action." As DeWitt and Graham (1971) so aptly put it, "physicists are, at bottom, a naive breed, forever trying to come to terms with the 'world out there' by methods which, however imaginative and refined, involve in essence the same element of contact

53 For possible answers to these questions see (Mohrhoff, 2002d, 2006, 2007).

as a well-placed kick."[54]

There is more that begins to make sense within a Vedantic framework of thought. Rule B (Section 2) instructs us to add the amplitudes associated with a set of alternatives. When it applies, the distinctions we make between these alternatives are distinctions that Nature does not make; they lack counterparts in the physical world. As a result, there are limits to the objective reality of the mind's distinctions (Section 6). When mind, the subordinate cosmic principle, is employed by supermind, the original creative principle, it is used judiciously. Its tendency to divide *ad infinitum* is checked. This is why there are limits to the objective reality of mental distinctions. On the other hand, when mind is separated in its self-awareness from its supramental parent and left to run wild, as it is in us, it not only divides *ad infinitum* but also takes the resulting multiplicity for the original truth or fact. This is why we tend to construct reality from the bottom up, on an intrinsically and completely differentiated space or space-time, out of locally instantiated physical properties, or else by aggregation, out of a multitude of individual substances. It is also why making sense of QM is so hard. Vedanta and QM agree, at a minimum, that the original truth is unity. By implying that physical reality is created top-down, by a differentiation of pure existence that does not bottom out (Section 8), QM is trying to tell us that the original creative principle is supramental rather than mental.

Because we insist on constructing the world from the bottom up — the macroscopic out of the microscopic — we are baffled by (if not blind to) the *supervenience* of the microscopic on the macroscopic (Section 11). The microworld of molecules, atoms, and subatomic particles is what it is because of what happens or is the case in the macroscopic world, rather than the other way round as we are prone to think. A property exists only if, only when, and only to the extent that its possession can be inferred from an actual event or state of affairs. A quantity has a value only if, only when, and only to the extent that a value is indicated. Even the Moon has a position only because (and only to the extent that) its position can be inferred from position-indicating events in the "rest of the world."

It is one thing to be able to follow the logic leading from the existence of objects that (i) "occupy" finite regions of space yet (ii) are "made" of finite numbers of objects that don't, to Nature's objective fuzziness (Section 3), and on to the *extrinsic* nature of physical properties (Section 4). It is quite another to come to terms with the implied holism. For the supermind, which senses and acts from global to local, by differentiating the

54 The principle of local action is regarded by many as sufficient justification for the transmogrification of a mathematical tool like the electromagnetic field or the space-time metric into a physical entity in its own right. The fallacy underlying this view is not hard to spot. Nonrelativistic physics imposes no restrictions on how soon distant effects can occur, as long as they are *later* than their causes. To ensure that effects are later than their causes, relativistic physics requires that the time between a cause and its effect be equal or greater than their distance divided by the speed of light; otherwise there are reference frames in which the effect is earlier than the cause. It follows that during infinitesimal times, only effects at infinitesimal distances can be produced. To conclude from this that effects at finite distances are compounded from actions across infinitesimal space-time intervals is a *non sequitur*.

whole rather than by aggregating parts, the dependence of the parts on the whole is a matter of course.

Here is another, perhaps somewhat easier way to make sense of the extrinsic nature of physical properties. If you experience something the like of which you never experienced before, you are obliged to describe it in terms of familiar experiences. It is much the same with the quantum world. If QM tells us how the world is manifested, rather than how things are put together, we should expect that what lies “behind” the manifested world — everything from *brahman* to molecules — can only be described (in fact, can only be *defined*) in terms of the finished product — the manifested world. QM affords us a glimpse “behind” the manifested world — the macroworld — at formless particles, non-visualizable atoms, and partly visualizable molecules, which, instead of being the world’s constituent parts or structures, are instrumental in its manifestation. Just as unfamiliar experiences can only be described in terms of familiar ones, that which lies “behind” can only be described in terms of what happens or is the case “in front.”[55]

Lastly, supermind is capable of at least two distinct poises of relation between self and world (Sri Aurobindo, 1987, Chap. XVI; Mohrhoff, 2007). In the primary poise (*vijñana*) the self is coextensive with the spatiotemporal whole; consciousness comprehends (and creates) the world aperspectively from everywhere and everywhen at once.[56] In the secondary poise (*prajñana*) the self adopts a multitude of standpoints that are localized both spatially and temporally. Consciousness apprehends and determines its own content perspectively from a multitude of locations and successively from what we call “the present.” Here, in this secondary supramental poise, we have the origin of our mental outlook. Once again the view that contemporary physics compels us to adopt — in this case the view from nowhere and nowhen — turns out to agree with the original poise of *chit-tapas.* McTaggart’s (1908) A–series temporality does not exist in the physical world because it does not exist in the primary poise of the supermind. It isn’t *as* objective as the content of the original creative consciousness (Mohrhoff, 2007).

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55 The (genuine) need to understand how “classicality” emerges from a quantum substrate is felt by many a quantum mechanician (e.g., Joos and Zeh, 1985; Pearle, 1979). Alas, the quantum substrate is invariably taken to consist in an ontologized version of the wave function, rather than something like the Vedantic *brahman.*

56 We must take care not to project the qualitative aspects of space and/or time into the spatiotemporal whole and draw conclusions from this projection. We know spatial extension as the general quale of every spatial whole, and we know temporal succession as the general quale of every temporal whole. But if there is a qualitative aspect to the spatiotemporal whole, we know nothing of it.

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