Is the end in sight for theoretical pseudophysics?

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Abstract
The question of what ontological message (if any) is encoded in the formalism of contemporary physics is, to say the least, controversial. The reasons for this state of affairs are psychological and neurobiological. The processes by which the visual world is constructed by our minds, predispose us towards concepts of space, time, and substance that are inconsistent with the spatiotemporal and substantial aspects of the quantum world. In the first part of this chapter, the latter are extracted from the quantum formalism. The nature of a world that is fundamentally and irreducibly described by a probability algorithm is determined. The neurobiological processes responsible for the mismatch between our “natural” concepts of space, time, and substance and the corresponding aspects of the quantum world are discussed in the second part. These natural concepts give rise to pseudoproblems that foil our attempts to make ontological sense of quantum mechanics. If certain psychologically motivated but physically unwarranted assumptions are discarded (in particular our dogged insistence on obtruding upon the quantum world the intrinsically and completely differentiated spatiotemporal background of classical physics), we are in a position to see why our fundamental physical theory is a probability algorithm, and to solve the remaining interpretational problems.
1 INTRODUCTION

According to the “minimal instrumentalist interpretation” [2], the mathematical formalism of quantum mechanics (QM) is an algorithm for assigning probabilities to the possible outcomes of measurements that may be made, on the basis of actual measurement outcomes. Is there more to QM than that? If QM is our fundamental theoretical framework, then the answer must surely be affirmative. But if the answer is affirmative, how can our fundamental theoretical framework be a probability algorithm? While a “mere” probability algorithm does not appear capable of describing the events to which it assigns probabilities, a fundamental theory must encompass these events as well as the correlations between them.

The first aim of this chapter is to show how QM can be both our fundamental theoretical framework and a “mere” probability algorithm. The task of determining the nature of a world that is fundamentally and irreducibly described by a probability algorithm, is carried out in Secs. 2–6 and resumed in Sec. 10. What transpires there is in conflict with some of our deepest convictions about space, time, and matter. The second aim of this chapter is to determine the psychological and neurobiological origins of this conflict, which is responsible for the difficulties we face in trying to make sense of QM. This task is undertaken in Secs. 7 and 9.

The visual world is constructed by our minds in conformity with the Cookie Cutter Paradigm, which 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. The most nefarious consequence of this biologically “hardwired” paradigm is our dogged insistence on obtruding upon the quantum world the intrinsically and completely differentiated spatiotemporal background of classical physics (Sec. 8). This, more than anything else, is responsible for the belief that the wave function represents an evolving instantaneous physical state, and hence for the mother of all pseudoproblems—how to explain (away) the discontinuous mode of evolution associated with measurements (Sec. 9). What obtains between two successive measurements is not an evolving physical state but a fuzzy state of affairs that is temporally undifferentiated (Sec. 10).

What remains of the so-called “measurement problem” (including the so-called “pointer problem”) when this is stripped of the notion that quantum states evolve, is solved in Sec. 11. Comments on three interpretative strategies (spontaneous localization theories, decoherence theories, and modal interpretations) are offered in Sec. 12. The penultimate section deals with the limits that QM imposes on explanations, and in the concluding
section I explain why I am afraid that the answer to the question posed in the title of this chapter is negative.

2 THE RELATIVE AND CONTINGENT REALITY OF SPATIAL DISTINCTIONS

Consider the probability distribution $|\psi(x)|^2$ associated with the position of the electron relative to the nucleus in a stationary state of atomic hydrogen. Imagine a small region $V$ for which $\int_V |\psi(x)|^2 dx$ differs from both 0 and 1. While the atom is in this state, the electron is neither inside $V$ nor outside $V$. (If the electron were inside, the probability of finding it outside would be 0, and vice versa.) But being inside $V$ and being outside $V$ are the only possible relations between the electron and $V$. If neither relation holds, this region simply does not exist for the electron. It has no reality as far as the electron is concerned. But conceiving of a region $V$ is tantamount to making the distinction between “inside $V$” and “outside $V$”. Hence instead of saying that $V$ does not exist for the electron, we may say that the distinction we make between “inside $V$” and “outside $V$” is a distinction that the electron does not make. Or we may say that the distinction we make between “the electron is inside $V$” and “the electron is outside $V$” is a distinction that Nature does not make. It corresponds to nothing in the physical world. It exists only in our heads.

Suppose, again, that the observables $A$, $B$, and $C$ are consecutively measured, the outcome of the first measurement being $a$. If the Hamiltonian is 0, the probability of finding $c$ after the intermediate measurement of $B$ is

$$ p (c|a, B) = \sum_i |\langle c|b_i\rangle \langle b_i|a\rangle|^2. \quad (1) $$

If the Hamiltonian is not 0, the brackets are transition amplitudes. Formula (1) applies whenever information concerning the value of $B$ is in principle available, however difficult it may be to obtain it. If such information is strictly unavailable, the probability of finding $c$ is

$$ p (c|a) = |\langle c|a\rangle|^2 = \left|\sum_i \langle c|b_i\rangle \langle b_i|a\rangle\right|^2. \quad (2) $$

Thus in one case we first calculate the absolute squares of the amplitudes $\langle c|b_i\rangle \langle b_i|a\rangle$ and then add the results, and in the other case we first add the amplitudes associated with the alternatives (which are defined in terms of possible measurement outcomes) and then square the absolute value of the result. Why? Because in one case the distinctions we make between the alternatives have counterparts in the physical world, and in the other case they don’t. To cite a familiar example, in one case the electron ($e$) goes through either the left slit ($L$) or the right slit ($R$). The propositions “$e$ went through $L$” and “$e$ went through $R$” possess truth values: one is true, the other is false. In the other case, these propositions lack truth values; they are neither true nor false but meaningless.
All we can say in this case is that it goes through $L\&R$, the region defined by the slits considered as a whole. We cannot say more than that because the distinction we make between “e went through $L$” and “e went through $R$” is a distinction that Nature does not make in this case. It has no counterpart in the actual world.

Thus whenever QM requires us to add amplitudes, the distinctions we make between the corresponding alternatives are distinctions that correspond to nothing in the physical world. This implies, in particular, that the reality of the spatial distinctions we make is relative and contingent. “Relative” because our distinction between the inside and the outside of a region may be real for a given object at a given time, and it may have no reality for a different object at the same time or for the same object at a different time; and “contingent” because the existence of a given region $V$ for a given object $O$ at a given time $t$ depends on whether the proposition “$O$ is in $V$ at the time $t$” has a truth value.

3 THE IMPORTANCE OF THE “MEASUREMENT APPARATUS”

Does this proposition have a truth value if none is indicated (by an actual event or state of affairs)? To find out, 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 at the same time? 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, the answer is negative. Regions of space do not exist “by themselves”. The distinction we make between “inside $W$” and “outside $W$” has no physical reality per se. If $W$ is not realized (made real) by some means, it does not exist. But if it does not exist, the proposition “$O$ is in $W$” cannot have a truth value. 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 $D$, $O$ would not be detected by $D$. Probability 1 is not sufficient for “is” or “has”.

It follows that a detector\(^1\) 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 to $O$. The apparatus that is presupposed by every quantum-mechanical probability assignment is needed not only for the purpose of indicating the possession, by a material object, of a particular property (or the possession, by an observable, of a particular value) but also for the purpose of realizing a set of properties or values, which thereby become available for attribution. This does not mean that QM is restricted “to be exclusively about piddling laboratory operations” [3]. 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.

\(^1\)A perfect detector, to be precise. If $D$ is less than 100 percent efficient, the absence of a click does not warrant the falsity of “$O$ is in $W$”.

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4 THE INCOMPLETE SPATIOTEMPORAL DIFFERENTIATION OF THE PHYSICAL WORLD

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

While positions are indicated by (macroscopic) detectors, times are indicated by (macroscopic) clocks. (The word “macroscopic” is defined in Sec. 11.) Since clocks indicate times by the positions of their hands, and since sharp positions do not exist, neither do sharp 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 sharp positions. Neither the spatial nor the temporal differentiation of the world goes all the way down.

5 SPACE AND MATTER: SELF-RELATIONS AND NUMERICALLY IDENTICAL RELATA

If two indistinguishable particles scatter elastically, the question of which incoming particle is identical with which outgoing particle, cannot be answered, as is well known. If we label the incoming particles $A$ and $B$ and the outgoing ones $C$ and $D$, there are two alternatives: $(A \to C, B \to D)$ and $(A \to D, B \to C)$. Since QM requires us to add their amplitudes, the distinction we make between them is a distinction that Nature does not make. The distinction between this particle and that particle (over and above the distinction between this property and that property) corresponds to nothing in the physical world.

For centuries philosophers have argued over the existence of distinct substances. QM has settled the question for good: there is only one substance; it is illegitimate to interpose a multitude of distinct substances between the substance that betokens existence and

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$^2$Digital clocks indicate times by transitions from one reading to another, without hands. The uncertainty principle for energy and time implies that such a transition cannot occur at an exact time, except in the unphysical limit of infinite mean energy [4].
the multitude of existing (“possessed”) positions. Distinctness is strictly a matter of properties. $A$, $B$, $C$, and $D$ label sets of properties, not substances. As a set of properties, each is distinct from the others. As substances, all are identical in the strong sense of numerical identity.

We thus arrive at the following conclusions: Space is not an intrinsically differentiated, pre-existent expanse, and matter is neither a collection of substantial fields nor a multitude of distinct substances. Instead, space is the totality of existing spatial relations ("possessed" relative positions and relative orientations), and matter is the corresponding apparent multitude of relata—apparent because the relations are self-relations.

But are not the relations embedded in a continuous, 3-dimensional expanse? And is not space this continuous expanse, rather than a set of relations? Here are two possible answers: (i) Spatial extension is a property of each spatial relation. What accounts for the spatial character of spatial relations is this property, rather than a pre-existent spatial expanse. If (in our minds) we abolish matter (the relata), we abolish space (the relations) as well, and what then remains is not a continuous expanse undifferentiated by relations but nothing (at any rate, nothing that is differentiated or extended). (ii) If we insist on thinking of spatial extension as the property of a substantial expanse, we must think of this expanse as intrinsically devoid of multiplicity. The divisions we tend to project into it correspond to nothing in the physical world. Since being extended and being undivided is a rather paradoxical combination of properties for a substance, I prefer the first answer.

6 THE TOP-DOWN STRUCTURE OF THE PHYSICAL WORLD

If all that space contains (in the proper, set-theoretic sense of “containment”) is spatial relations, then the form of a material object is the set of its internal spatial relations (the relative positions and orientations of its constituents), and a particle without internal structure (no constituents, no internal spatial relations) is a formless object. Particles without internal structure are often said to be pointlike instead. There are several reasons why this should not be taken to mean more than that fundamental particles lack internal structure.

To begin with, nothing in the formalism of QM refers to the shape of an object that

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3Even such a seemingly harmless expression as “possessed position” is seriously misleading, inasmuch as it suggests the existence of a multitude of position-possessing substances. There is only the substance that warrants the existence of positions, and this is the same for all existing (“possessed”) positions.

4Hence there is no such thing as empty space—not because space is “filled with vacuum fluctuations”, as some say, but because there are no unoccupied locations or unpossessed positions. Where there is nothing (no thing) there is no “there”.

5It 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 on account of its failure to accommodate inertial effects. See Refs. [5, 6] for a refutation of this claim.
lacks internal structure, and empirical data cannot possibly do so. (While experiments may produce evidence that a particle has structure, they cannot produce evidence that a particle lacks structure. A fortiori they cannot produce evidence that a particle has a pointlike form.) The notion that an object without internal structure has a form (which would have to be pointlike) is therefore unwarranted on both theoretical and experimental grounds. 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. Instead of contributing something to our understanding of empirically accessible forms, the notion that a structureless particle is a pointlike object encumbers us with a form that is (i) entirely unverifiable, (ii) explanatorily completely useless, and (iii) absolutely different from all empirically accessible forms, which are sets of spatial relations. All we can possibly gain from postulating that a structureless particle has a (pointlike) form, is the assurance that quarks and such can be visualized (if we allow that a point can be visualized). What good does that do, considering that atoms (the smallest things “made of” structureless quarks and structureless electrons) can not be visualized as they are? It is to the bigger things, starting with molecules, that we can attribute something like a form that can be visualized as it is, not to the smaller things that make up atoms.

According to Bertrand Russell [7], “substance” is a metaphysical mistake, due to transference to the world-structure of the structure of sentences composed of a subject and a predicate. If we let QM have its say, substance is anything but a mistake. There is something that constitutes matter and space but remains undivided by its space-constituting self-relations and the corresponding multitude of matter-constituting relata. Since this is the only “thing” that exists independently of anything else, “substance” is the appropriate word, and even capitalization is warranted.

What is a mistake is the attempt to build reality “from the bottom up”, on an intrinsically and infinitely differentiated space or spacetime, out of locally instantiated physical properties, or else by aggregation, out of a multitude of distinct substances. Reality is built “from the top down”, by a self-differentiation of one Substance. By the simple device of entering into spatial relations with itself, this creates both space (the existing spatial relations) and matter (the corresponding relata). The reason why we cannot built reality from the bottom up is that this top-down differentiation does not “bottom out”. If we go on dividing a material object, its “constituents” lose their individuality, and if we conceptually partition the physical world into sufficiently small yet finite regions, we reach a point where the distinctions we make between these 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 spatial distinctions.
Let us now examine the neurobiological reasons why these ontological implications of QM go counter to some of our deepest convictions concerning space, time, and matter.

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. 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 “the Cookie Cutter Paradigm” (CCP) [8, 9].

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. Vision is now widely recognized as a process of reconstruction: From optical images at the eyes, human vision reconstructs those properties of the physical world that are useful to the viewer [10]. 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 [11]. Further downstream, in the primary visual cortex (V1), most cells are orientation selective (in the macaque monkey about 70 to 80 percent); the rest have center-surround receptive fields and are color selective [12]. 10 to 20 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 [12, 13]. Since all visual information flows through these cortical regions, it is 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 outlines, then outlines are supplemented with covering surfaces much like the wire frames of CAD software.

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

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6Orientation 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.
of the physical world should conform to the CCP—and that we should be perplexed by Nature’s refusal to follow suit. To my mind, the formidable interpretational problems associated with QM are largely due to an unreflecting refusal to think about the physical world along other lines than those laid down by the CCP. Let us now 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 we come to think of space as a pre-existent and intrinsically divided expanse. But if this is how we think, 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 centre-of-mass.) In other words, all possessed positions are sharp.

There are more ways in which our neurobiology misleads 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. The reasons for these disparate attitudes are to be found in the neurobiology of perception. They have nothing to do with the quantum world, other than making it hard to make sense of it.

One of these reasons is the following: 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. 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 signalled by neurons from one feature map, and “boxy here” and “round there” are signalled 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. In the brain, and consequently in the phenomenal world, positions pre-exist—in the brain at the scale 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.\footnote{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 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. This analogy is another reason why we tend to think of positions as substances.}

The accompanying table contrasts the salient features of the quantum world with the corresponding features of a world that is constructed along the lines laid down by the CCP. Not every one of the features in the right column can be directly linked to the CCP, though. The notion that objects without spatial extent must have (pointlike) forms arises if objects are treated as \textit{phenomenal} objects, since formless objects cannot \textit{appear}. And the notion that the ultimate constituents of matter are distinct substances is bolstered by the following facts: (i) since phenomenal features that are present in the same place get integrated into the same phenomenal object, different phenomenal objects cannot be in the same place, (ii) phenomenal objects are macroscopic, (iii) macroscopic objects change in ways that ensure that they are re-identifiable.

Nor is it to be expected that anyone would try to incorporate all of the items in the right column in his or her model of the physical world, not least because some of them are mutually inconsistent. For instance, if the ultimate constituents of matter are pointlike, the shapes of things with spatial extent cannot be surfaces. Yet, to the best of my knowledge, the interpretation outlined in this chapter is the only one that rejects all of those items. Specifically, the postulate of an intrinsically and completely differentiated, pre-existent spatial or spatiotemporal expanse appears to be shared by all other models.

8 SPACE, TIME, AND THE WAVE FUNCTION

It strikes me as odd that the ontological and/or epistemological status of the wave function has been the focus of a lively controversy for three quarters of a century, while the ontological status of the coordinate points and instants on which $\psi(x,t) = \langle x|\psi(t) \rangle$ functionally depends has hardly ever been called in question.

Consider the state $|z_+\rangle$. It is a shorthand notation for the projector $|z_+\rangle\langle z_+|$ representing (i) a possible outcome of a measurement of the $z$ component of the spin of (say) an electron and (ii) the density operator “prepared” by this outcome. It informs us of the outcome of a measurement, and it allows us to compute the probabilities of the possible
## A TA(B)LE OF TWO WORLDS

| 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 an intrinsically and completely differentiated, pre-existent expanse.               |
| The only existing positions are the relative positions between 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; they are intrinsic to a pre-existent expanse.|
| The spatial character of spatial relations is a property shared by all spatial relations. | The spatial character of spatial relations derives from a pre-existent expanse, in which the relations are embedded. |
| A structureless particle, lacking spatial extent, is a formless object.                  | A structureless particle, lacking spatial extent, 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 surface.                                     |
| Considered by themselves, the ultimate constituents of matter are identical in the strong sense of numerical identity. Each is the one Substance that constitutes every material object. | The ultimate constituents of matter are distinct substances.                                |
| The spatiotemporal differentiation of the world is incomplete.                          | The spatiotemporal differentiation of the world is complete.                                |
| Owing to its incomplete spatiotemporal and substantial differentiation, the world has a top-down structure. | The world is built from the bottom up, on an intrinsically and completely differentiated manifold or out of a multitude of distinct substances. |
outcomes of subsequent measurements. Nothing can be said without reference to measurements. Why? Because an “apparatus” is needed to realize an axis. By realizing an axis, the apparatus makes available two possible values; it creates possibilities to which probabilities can be assigned. In its absence, the properties “up” and “down” do not even exist as possibilities. The notion that the symbol $|z_+\rangle$ represents something as it is, rather than as it behaves in any given measurement context, is wrong.

The same goes for $\psi(x,t)$. As we saw in Sec. 3 in the absence of a detector that realizes a region $V$, or the distinction between “inside $V$” and “outside $V$”, the properties of being inside $V$ and being outside $V$ do not even exist as possibilities.

Alas, the existence of an intrinsically and completely differentiated, pre-existent space or spacetime appears to be taken for granted by all ontologizing interpreters of QM. In view of the incomplete spatiotemporal differentiation of the physical world implied by the quantum formalism itself, it should therefore come as no surprise that the interpretation of QM is beset with pseudoquestions and gratuitous answers. As long as the existence of an intrinsically and completely differentiated background spacetime is assumed, it is safe to say that our attempts to beat sense into QM are doomed.

9 THE PSYCHOLOGY OF QUANTUM STATE EVOLUTION

In addition to the neurobiological reasons why we are prone to think of space (and therefore of spacetime as well) as an intrinsically differentiated expanse, there are strong psychological reasons why we are prone to think of time as intrinsically differentiated. In brief: while the successive nature of our experience makes it natural for us to hold that only the present is real, or that it is somehow “more real” than the future and the past, our self-experience as agents makes it natural for us to hold that the known or in principle knowable past is “fixed and settled”, while the unknown future is “open”.

Because it is impossible to consistently project the experiential Now into the physical world, none of this has anything to do with physics. 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 the same as true of the experiential Now: it has no counterpart in the physical world. There simply is no objective way to characterize the present. 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 sensory qualities, or through anticipation. In the physical world, 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 idea that

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8 We will see in a moment why these reasons cannot be neurobiological.

9 This is why the special experiential character of the present, which induces us to think of time as intrinsically differentiated, cannot be understood in neurobiological terms.
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.\textsuperscript{10}

In the physical world, time does not “flow” or “pass”. To philosophers, the perplexities and absurdities entailed by the notion of a changing objective present or a flowing time are well known. (See, e.g., the illuminating entry on “time” in Ref. [15].) To physicists, the subjectivity of a temporally unextended yet persistent and continually changing present was brought home by the relativity of simultaneity. The same is implied by QM, inasmuch as the incomplete differentiation of the quantum world rules out the existence of an evolving \textit{instantaneous} physical state.

Again, the physical correlation laws (whether classical or quantum) know nothing of a preferred direction of causality. They are time-symmetric. They permit us to retrodict as well as to predict. The figment of a causal arrow is a projection, into the physical world, of our sense of agency, our ability to know the past, and our inability to know the future. It leads to the well-known folk tale according to which causal influences reach from the nonexistent past to the nonexistent future through persisting “imprints” on the present: If the past and the future are unreal, 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 evolve in time (and therefore, in a relativistic world, according to the principle of local action), and that mediate between the past and the future (and therefore, in a relativistic world, between local causes and their distant effects). Classical electrodynamics is a case in point. While at bottom it is nothing but an algorithm for calculating the effects that electrically charged objects have on electrically charged objects, the projection of an evolving instantaneous state into the world of classical physics forces us to transmogrify this algorithm into a continuous, local, physical process by means of which effects are produced.

The projection of an evolving instantaneous state into the world of quantum physics forces us to seize instead on a probability algorithm that depends on the relative times between measurements and on the outcomes of earlier measurements, to transmogrify

\textsuperscript{10}If we conceive of temporal or spatiotemporal relations, we conceive of the corresponding relata simultaneously—they exist at the same time \textit{in our minds}—even though they happen or obtain at different times in the physical world. 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 and the present as advancing through it. 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.
the same into an instantaneous physical state, and to think of its evolution as a physical
process that plays a similar mediating role.

The all but universally accepted projection into the quantum world of the intrinsically
differentiated time “continuum” of classical physics made it a foregone conclusion that
ψ would come to be thought of as an evolving, instantaneous physical state. Since von
Neumann’s influential work[16], textbooks list versions of the following claims among the
axioms of QM:

(X) Between measurements, quantum states evolve according to unitary transforma-
tions (or according to trace-preserving completely positive linear maps) and thus
continuously and predictably.

(Y) By way of measurement, quantum states evolve as stipulated by the projection pos-
tulate (or, up to normalization, via outcome-dependent completely positive linear
maps) and thus in general discontinuously and unpredictably.

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 (standard) QM is the
postulation of two modes of evolution rather than one. Unitary evolution is considered
“normal” and therefore not in need of explanation. Hence the mother of all pseudo-
problems: how to explain (away) the unpredictable “collapses” of wave functions due to
measurements?

Stripped of the notion that quantum states evolve, (X) and (Y) merely state the ob-
vious. 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 times of measurements. (If you change the time of a 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 assign-
ment basis. (If you take into account an outcome that was not previously taken into
account and had a prior probability less than 1, the assignment basis changes unpredict-
dably as a matter of course, and so do the probabilities assigned.)

10 THE WORLD BETWEEN MEASUREMENTS

There is a notion that probabilities are inherently subjective, and that therefore QM qua
probability algorithm is an epistemic theory concerned with knowledge or information.[17]
[18]. It does not yield a model of a “free-standing” reality.[19]. This is wrong. That
probabilities are inherently subjective, is a wholly classical idea. The very fact that the
fundamental theoretical framework of contemporary physics is a probability algorithm,
signals that the probabilities it serves to assign are objective [20][21]. They are inevitable
ingredients in any adequate description of the quantum world. Subjective probabilities
are ignorance probabilities. They enter the picture when relevant facts are ignored. 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 totality of earlier measurement outcomes is insufficient for predicting subsequent measurement outcomes with certainty. The stability of ordinary matter—the existence of objects that have spatial extent, are composed of a (large but) finite number of objects without spatial extent, and neither collapse nor explode as soon as they are created—hinges on the objective fuzziness of their internal relative positions and momenta, not on our subjective uncertainty about the values of these variables. (The literal meaning of Heisenberg’s “Unschärfe” is “fuzziness”.)

What is the proper (i.e., mathematically rigorous and philosophical sound) way of describing fuzzy variables? It is to assign objective probabilities (not to be confused with relative frequencies) to the possible outcomes of measurements. Consider again the spin “state” \(|z_+\rangle\). Suppose that after the measurement that warrants the use of this algorithm, no further measurement is made. There is a notion that if QM concerns nothing but correlations between measurement outcomes, nothing can be said about the actual state of a spin (or any other system, for that matter) if no measurement is actually made. This, too, is wrong. While it is correct that nothing can be said without reference to measurements, a complete description of the fuzzy state of affairs that obtains after the measurement can be given; it consists in the probabilities that \(|z_+\rangle\) assigns to the possible outcomes of unperformed measurements \([23, 24]\). \(|z_+\rangle\) describes a fuzzy orientation by means of counterfactual probability assignments that vary continuously from 1 (for “up along the \(z\) axis”) to 0 (for “up along the inverted \(z\) axis”) as the axis of measurement (defined by the gradient of \(|B|\)) is rotated by 180° about any axis perpendicular to the \(z\) axis. At any rate, this is the fuzzy state of affairs that obtains after a measurement has yielded the outcome \(z_+\) if the Hamiltonian is 0, and if no further measurement is subsequently made.

If the Hamiltonian is not 0, then the probability assignments describing the subsequent fuzzy state of affairs depend on the times of (unperformed) measurements. This is not the same as saying that the subsequent fuzzy state of affairs changes with time, for the antecedents of these counterfactual probability assignments are false not only because they affirm that a measurement is made, but also because they affirm that this is made at a particular time. Where the electron’s spin is concerned, there is no particular time until another measurement is made. The quantum world is built from the top-down (Sec. 6), and temporal as well as spatial distinctions are relative and contingent (Sec. 2). The electron’s spin is temporally differentiated by the events that indicate its values. Between actual measurements it is only counterfactually differentiated (by unperformed

\[11\] If one looks for an appropriate formalism for quantifying the fuzziness that “fluffs out” matter, one is lead more or less directly to the probability algorithm of standard QM [22]—another good reason why the quantum formalism is fundamentally and irreducibly a probability algorithm.
measurements).

If another measurement is subsequently made, the fuzzy state of affairs that obtains in the meantime (during which no measurements are made) is fully described only if all relevant information is taken into account. This includes the outcome of the subsequent measurement. (Probability assignments based on earlier and later measurement data are made according to the ABL rule [20, 21].)

How can a measurement outcome contribute to determine a state of affairs that obtains during an earlier time? This ceases to be a mystery if the following points are taken into account. (i) There is no instantaneous physical state that evolves and thereby introduces an arrow of time. (ii) The relevant laws are time-symmetric. Born probabilities can be assigned on the basis of later as well as earlier outcomes, and ABL probabilities are by nature time-symmetric. Measurement outcomes can therefore be used to assign probabilities to the possible outcomes of unperformed measurements before, after, and between actual measurements. And these assignments can contribute to describe the fuzzy states of affairs that obtain before, after, and between actual measurements. As said, the notion that later states of affairs are determined only by earlier states of affairs is nothing but a psychological projection of our self-experience as agents in a successively experienced world.

An arrow of time does exist, but it pertains to the causal nexus in which measurements or value-indicating events (VIEs) are embedded (see Sec. 11). For inasmuch as VIEs create traces or records (which is necessary for their being value-indicating events) they are causally linked to the future, and there are two senses in which they are causally decoupled from the past. For one, the particular outcome of a successful measurement is generally not necessitated by any antecedent event. For another, nothing guarantees the success of an attempted measurement. Since every quantum-mechanical probability assignment presupposes the (actual or counterfactual) occurrence of a VIE, QM cannot supply sufficient conditions for the occurrence of a VIE.12 VIEs are uncaused.13

The bottom line: What obtains between measurements is what is appropriately described by counterfactual probability assignments, namely, fuzzy states of affairs. Like the probability measure that describes it, a fuzzy state of affairs is not something that evolves. It is not only fuzzy but also temporally undifferentiated.

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12While this implies that perfect detectors are a fiction, it does not prevent us from invoking perfect detectors to assign probabilities to the possible outcomes of unperformed measurements.

13But isn’t the click caused by the ionization of an atom in the counter? No, for while it is true that without an ionization there would be no click, it is equally true that without a click there would be no ionization 23 25. The microworld supervenes on the macroworld.
11 THE PROBLEM OF FACTUALITY

A fundamental physical theory that is essentially an algorithm for assigning probabilities to VIEs on the basis of other VIEs presupposes the occurrence of VIEs, and the challenge is to demonstrate that such a theory can be complete, in the sense that it not only presupposes but also encompasses the VIEs. The challenge is not to explain how possibilities—or worse, probabilities—become facts, how properties emerge, or why events occur. Saying in common language that a possibility becomes a fact is the same as saying that something that is possible—something that can be a fact—actually is a fact. This non-problem becomes a pseudoproblem if the common-language “existence” of a possibility is construed as a lesser kind of existence—a matrix of “propensities” or “potentialities” that transform into the genuine article by way of measurement. It is the sort of problem that is bound to arise if one misconstrues a probability algorithm as an evolving physical state. Our task as measurement theorists is not to account for the occurrence of VIEs, but to identify that substructure of the theoretical structure of QM which encompasses the VIEs, and which can be consistently considered factual per se.

Here goes: 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. 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 extremely 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.

Decoherence investigations have demonstrated for various reasonable definitions of “macroscopic” that the probability of finding a macroscopic object where classically it could not be, is extremely low. This guarantees the abundant existence of macroscopic objects according to the present, stricter definition, which are never actually “found” where classically they could not be. The correlations between the indicated positions of these objects are deterministic in the following sense: their fuzziness never evinces itself through outcomes that are inconsistent with predictions that are based on earlier outcomes and a classical law of motion. Macroscopic objects (including pointers) follow trajectories that are only counterfactually fuzzy. That is, they are fuzzy only in

14Because VIEs are uncaused, this is as impossible as explaining why there is anything at all, rather than nothing.
 relation to an imaginary background that is more differentiated spacewise than is the actual physical world. In the latter, there are no regions over which they are “smeared out”. So we cannot say that they are fuzzy—nor can we say that they are sharp: “not fuzzy” implies “sharp” only if we postulate the intrinsically and completely differentiated background space that the quantum world lacks.

To be able to identify a substructure of the theoretical structure of QM that can be consistently considered factual per se, 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. The reason why this is both possible and legitimate, is that the extrinsic nature of the values of physical variables is implied by their fuzziness. If macroscopic positions aren’t fuzzy, we have every right to consider them intrinsic—notwithstanding that they are also extrinsic, for even the Moon has a position only because of the myriad of “pointer positions” that betoken its whereabouts. The reason why macroscopic positions can be both extrinsic and intrinsic is that they indicate each other so abundantly, so persistently, and so sharply that they are only counterfactually fuzzy.

While the extrinsic nature of macroscopic positions forbids us to think of an individual macroscopic position as intrinsic or real per se, nothing stands in the way of attributing to the entire system of macroscopic positions an independent reality, and nothing prevents us from considering the entire system of existing spatial relations or possessed relative positions (including the corresponding multitude of relata) as self-contained. What the extrinsic nature of the properties of the quantum world forbids is to model this world from the bottom up. The macroscopic does not supervene on the microscopic, whether conceived as a multitude of substances or as a transfinite manifold of spacetime points. The “foundation” is above. The properties of the microworld exist because they are indicated by the goings-on in the macroworld. They supervene on the macroworld—the system of macroscopic positions, in which value-indicating events occur as unpredictable transitions, in compliance with the quantum-mechanical correlation laws.

The system of macroscopic positions thus is a substructure in two senses: it is a part of the entire theoretical structure of QM, and it is the self-existent foundation on which all indicated values supervene. What makes the macroworld the sole candidate for the predicate “factual per se” is the physical unreality of its own fuzziness or (equivalently) the fact that the spatial differentiation of the physical world is incomplete. Even though there is no hermitian “factuality operator” (factuality cannot be measured), QM thus uniquely determines what is factual per se. Owing to the crucial role played the incomplete spatial differentiation of the physical world, however, this cannot be seen, and therefore the notorious measurement problem cannot be solved, as long as a completely differentiated spatial background is postulated.
In discussions of the measurement problem, the following unitary “transition” usually plays as central role:

$$\sum_i c_i |q_i\rangle \otimes |A_0\rangle \rightarrow \sum_i c_i |q_i\rangle \otimes |A_i\rangle.$$  \quad(3)

$A_i$ is the property whose possession, by an apparatus $A$, indicates that a system $S$ has the property (or an observable $Q$ has the value) $q_i$, and $A_0$ is the apparatus-property of being in the neutral state. This substitution of one probability measure for another takes care of the time between a pair of measurements informing us how $A$ and $S$ are “prepared”, and another pair of measurements performed on $A$ and $S$, respectively, without taking into account the outcomes of these later measurements. Because of the perfect correlations between their possible outcomes, we are entitled to interpret the possession (by the apparatus) of a particular $A_i$ as indicating the possession (by the system) of the corresponding $q_i$, and because the apparatus-properties $A_i$ involve macroscopic positions, we are entitled to regard one (and only one) $A_i$ as possessed.

If the substitution (3) is misconstrued as a physical transition from the initial state of affairs $\sum_i c_i |q_i\rangle$ to the final state of affairs $\sum_i c_i |q_i\rangle \otimes |A_i\rangle$, the following pseudoquestions arise: How is it that measurements appear to have outcomes? And why does the outcome correspond to an element of this particular decomposition of the final state?

The decomposition of the final algorithm (3) is biorthogonal: the kets $|q_i\rangle$ are mutually orthogonal because $Q$ is hermitian, and the kets $|A_i\rangle$ are mutually orthogonal because $A$’s possession of $A_i$ indicates not only the truth of “$Q$ has the value $q_i$” but also the falsity of “$Q$ has the value $q_k$” for $k \neq i$. Modal interpretations (MIs) [1, 35, 36] capitalize on the uniqueness of the biorthogonal decomposition in the event that all $c_i$ have different norms. To ensure that one element of the decomposition represents reality, MIs simply postulate that whenever a two-component system has a unique biorthogonal decomposition, exactly one term of this decomposition represents the actual state of the system.

Spontaneous localization theories (SLTs) [37, 38, 39] introduce nonlinear or stochastic modifications of the standard dependence of probabilities on the times of measurements, in order to ensure that the probabilities associated with value-indicating pointer positions are either close to 1 or close to 0—needless to say, without enabling us to predict which pointer position will be the lucky one; betting on outcomes remains guided by the Born probabilities of standard QM.

Decoherence theories (DTs) [27, 40] capitalize on the fact that all known interaction Hamiltonians contain $\delta$-functions of the distances between particles. This makes the environment a more accurate monitor of pointer positions than any individual apparatus could be. Individual measurements of pointer positions therefore reveal pre-existent properties, in the sense that they indicate properties that are monitored by the environment. \footnote{In the vocabulary of decoherence theorists, “monitored by the environment” is synonymous with...}
One common characteristic of these interpretative strategies is that an ever so small quantitative difference is held to be sufficient for a considerable conceptual difference. Consider a biorthogonal probability measure.

\[ a_1|\phi_+\rangle \otimes |\psi_+\rangle + a_2|\phi_-\rangle \otimes |\psi_-\rangle \] (4)

If the norms of the coefficients \( a_1 \) and \( a_2 \) differ ever so little, then, according to MIs, one element of this decomposition represents the actual state. Otherwise they don’t. An ever so slight difference thus can decide whether or not a value exists. SLTs (like many other approaches) subscribe to the notion that probability 1 is necessary and sufficient for “has” or “is”. This means that the radical difference between either “has” or “lacks” and “neither has nor lacks” can hinge on an ever so slight difference between a probability equal to 1 and a probability less than 1. DTs are motivated by the belief that the vanishing of off-diagonal terms is necessary and sufficient for the reinterpretation of a density operator as a proper mixture. An ever so small difference between = and \( \approx \) can therefore make the enormous conceptual difference between “and” and “or”.

Another unpalatable feature of the interpretative strategies considered here arises as a consequence. These strategies countenance a conceptual fuzziness that permits \( \approx \) to do duty for =. The probabilities of VIEs in SLTs are never exactly 1 (the relevant probability distributions have “tails”). DTs succeed in demonstrating that the relevant off-diagonal terms remain very small for very long times but not that they remain 0 for all time to come. MIs need to demonstrate that the final algorithm in (3) is biorthogonal. But this is tantamount to demonstrating that the off-diagonal terms vanish, as one gathers from the final density operator associated with \( S \),

\[
\sum_{ij} c_i c_j^* \langle A_j | A_i \rangle |q_i\rangle \langle q_j|,
\] (5)

which is diagonal (regardless of the values of the \( c_i \)) if and only if \( \langle A_j | A_i \rangle = 0 \) for \( i \neq j \).

This conceptual fuzziness, as d’Espagnat has argued at length and convincingly [41, 42, 43], is unacceptable in a strongly objective theory. Therefore, so d’Espagnat, QM is an objective theory only in a weak, intersubjective sense of “objective”. Similar qualifications have been made by many other authors. While Zurek advocates a twofold relativization of “existence” [32, 40, 44], Zeh [45] argues that “[w]hile decoherence transforms the formal ‘plus’ of a superposition into an effective ‘and’ (an apparent ensemble of new wave functions), this ‘and’ becomes an ‘or’ only with respect to a subjective observer”. Such qualifications become necessary only if the world’s incomplete spatiotemporal differentiation (implied by the fuzziness of all relative positions) is ignored and a completely differentiated background spacetime is postulated instead. The choice is between fuzziness in the head or fuzziness in the world.

something like “decoherently correlated with the environment”.
13 THE LIMITS OF EXPLANATION

Can we hope to explain the quantum-mechanical correlation laws? If these laws are indeed the fundamental laws of physics (and apart from our dogged insistence on explaining from the bottom up, we have no reason to believe that they are not), then they cannot be explained the way Kepler's laws of planetary motion can be explained by Newton's law of gravity. Only a law that is not fundamental can be so explained. What is more, QM does not permit us to decompose the quantum world into a multitude of interacting substances with causally connected properties. The explanatory framework provided by these concepts, so useful for our dealings with the phenomenal world, cannot be expanded to include more than the macroworld. To look for causal explanations of the quantum-mechanical correlations is to put the cart before the horse. It is the fundamental correlation laws that define the extent to which causal concepts may be used.

Can we interpret the quantum-mechanical correlation laws as descriptive of a mechanism or physical process? As far as the synchronic correlations ("EPR correlations") are concerned, this possibility seems too remote for serious consideration. One only has to consider the state of three spin-1/2 particles discussed Greenberger, Horne, and Zeilinger [46]. If this state is prepared, it is possible to predict any spin component of any particle by subjecting the two other particles to appropriate measurements, even though the correlations between the possible outcomes of spin measurements are independent of the distances between the three particles, and even though it is impossible to think of these measurements as revealing pre-existent values. It is hoped that this chapter has made it clear why attempts at interpreting the diachronic correlation laws as descriptive of some physical process, are equally misguided.

There remains the question of how the correlations are possible at all. We tend to believe, as Einstein did, that "things claim an existence independent of one another" whenever they "lie in different parts of space" [47]. If this were true, the correlations would indeed be impossible. Fact is that the three particles, irrespective of the distances between them, are not independent of one another. Fiction is that they lie in different parts of space. In the quantum world, space has no parts, whether we think of space as a set of relations (a set of relations has no parts) or as a pre-existent expanse (QM does not permit us to think of it as divided). The quantum world, moreover, has room for only one substance. Considered by themselves, the ultimate constituents of matter are identical in the strong sense of numerical identity. All existing relations are self-relations. How, then, could things possibly "claim an existence independent of one another"?

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 [47]. This is ironic, for it is precisely the illegitimate projection of the structure of the phenomenal world into the physical world that underlies this belief. In the phenomenal world, which is constructed in conformity with the CCP, places pre-exist (Sec. [47]), and features that are present in different places get integrated into different phenomenal
objects (which may be parts of the same object). This is why we are convinced by default that whatever exists in different places must be different objects. If the perceived 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 we give the grand name “principle of local action”.

14 CONCLUSION

At present, the physics community can be divided into three factions. The first—the majority—doesn’t care very much what (if anything) QM is trying to tell us about the nature of Nature. The second resigns itself to agnosticism. It asserts that we cannot describe the quantum world as it is (by itself): its features are forever beyond our ken. All we can usefully talk about is statistical correlations between measurement outcomes. The third aspires to describe the quantum world as it is, independent of measurements. This faction is split into numerous sects, each declaring to see the light, the ultimate light. Go to any conference on quantum foundations, and you will find their priests pitted in holy war.

The agnostics and the priests both have a point and both are wrong. The agnostics have a point in that nothing of relevance can be said without reference to measurements. They are wrong in claiming that the features of the quantum world are beyond our ken. The priests have a point in that it is indeed possible to describe the features of the quantum world. They are wrong in claiming that these features can be described without reference to measurements.

We have examined some of the neurobiological and psychological reasons for this sorry state of affairs. Because of them, it is virtually impossible to recognize the ontological implications of QM or (if they are recognized) to accept them. To many they might seem as preposterous as the metaphysical claims of the quantum-state realists. We shall therefore continue to hear claims to the effect that “quantum theory does not describe physical reality. What it does is provide an algorithm for computing probabilities for the macroscopic events (“detector clicks”) that are the consequences of our experimental interventions” [19, original emphasis]. And we shall be told that it is impossible to distill from QM a model of a free-standing reality independent of our interventions.

Yet agnosticism is nothing but a cop-out. Science is driven by the desire to know how things really are. It owes its immense success in large measure to its powerful “sustaining myth” [50]—the belief that this can be discovered. Neither the ultraviolet catastrophe nor the spectacular failure of Rutherford’s model of the atom made physicists question

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16 "[P]hysicists 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 as a well-placed kick" [18].
their faith in what they can achieve. Instead, Planck and Bohr went on to discover the quantization of energy and angular momentum, respectively. If today we seem to have reason to question our “sustaining myth”, it ought to be taken as a sign that we are once again making the wrong assumptions, and it ought to spur us on to ferret them out. We may yet have to learn how to reconcile a free-standing reality with the supervenience of the “quantum domain” on the macroworld, but how could anyone know that it is impossible? It is, in fact, quite possible, provided we cease to obtrude upon the quantum world the intrinsically and completely differentiated spatiotemporal background of classical physics.

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