On the Cognitive Status of Our Best Physical Theories

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Abstract: There is good reason to suppose that our best physical theories are false: In addition to its own internal problems, the standard formulation of quantum mechanics is logically incompatible with special relativity. There is also good reason to suppose that we have no concrete idea concerning what it might mean to claim that these theories are approximately or vaguely true. I will argue that providing a concrete understanding the approximate or vague truth of our current physical theories is not a task for traditional epistemology; rather, this is only possible in the context of ongoing empirical inquiry. [Note #1]

I. Introduction

It is customary to imagine that our best physical theories are true, probably true, or probably approximately true. The received view among physicists concerning the cognitive status of our best physical theories is well-expressed by Isaac Newton in Rule IV of his *Rules for the Study of Natural Philosophy*:

> In experimental philosophy, propositions gathered from phenomena by induction should be considered exactly or very nearly true not withstanding any contrary hypothesis, until yet other phenomena make such propositions either more exact or liable to exceptions. (Newton 1999, 796)

Newton allows here for the possibility that his mechanics might be made more accurate or liable to exceptions, but he did not believe that it might be radically false.

Whether Newtonian mechanics should be taken to be approximately true or radically false as a description of the physical world depends on what one cares about. There are indeed ways in which it might be taken to be a limiting case of our current best physical theories. On the other hand, Newton did not have the conceptual tools needed even to express the basic principles on which our current best physical theories are built (which employ concepts like *superposition* and *spacetime*). Newtonian mechanics then approximates our best current physical theories in some ways but is radically different from these theories in other ways. So what is the proper cognitive status of our best current physical theories?

Quantum mechanics and special relativity are the two cornerstones of modern physics. Together (in the context of Quantum Electrodynamics for example) they provide the most accurate empirical predictions we have ever had. But are they true, probably true, or probably approximately true as descriptions of the physical world? There is good reason to answer the first two parts of this question with no. And the third part depends on what one means by approximately true.

The standard von Neumann-Dirac collapse formulation of quantum mechanics is logically inconsistent on a strict, uncharitable reading; and it is inconsistent with special relativity in a perfectly straightforward sense. Moreover, it is unclear how to get a consistent description of the physical world out of the two theories, and the various alternative proposals for how one might get started on this project suggest radically different physical worlds. Consequently, we have good reason to suppose that the standard formulation of quantum mechanics and special relativity considered together are false, and it is difficult to say how they might be taken to be approximately true.

Note that the argument here that our best physical theories are false does not depend on any special philosophical skepticism nor on a pessimistic induction on our past scientific failures. Rather, we have good reason to believe that our best current physical theories are false on the basis of their internal structure and mutual incompatibility.

Insofar as scientific knowledge is our best empirical knowledge, and physical theories are thought to be a paradigm of scientific knowledge, we should expect to learn something about the fundamental nature of our best empirical knowledge by considering the cognitive status of our best physical theories.

II. The Standard Collapse Formulation of Quantum Mechanics

The standard collapse formulation of quantum mechanics, which is still the one presented in most textbooks, was first described by P. A. M. Dirac and John von Neumann in the early 1930s (von Neumann 1955). This theory was an attempt to unify the earlier theoretical work of Heisenberg and Schroedinger and the interpretational insights of Max Born. The standard formulation of quantum mechanics can be summarized as follows:

> **1. Representation of States**: The possible physical states of a system *S* are represented by the unit-length vectors in a Hilbert space (which for present purposes one may regard as a vector space with an inner product). A vector in the Hilbert space represents the physical state at a time.
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> **2. Representation of Properties**: For each physical property *P* that one might observe of a system *S* there is a linear operator ***P*** (on the vectors that represent the possible states of *S*) that represents the property.
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> **3. Eigenvalue-Eigenstate Link**: A system *S* determinately has physical property *P* if and only if ***P*** operating on ***S*** (the vector representing *S*'s state) yields ***S***. We say then that *S* is in an eigenstate of ***P*** with eigenvalue 1. *S* determinately does not have property *P* if and only if ***P*** operating on ***S*** yields 0.

4. Dynamics: **(a)** If no measurement is made, then a system *S* evolves continuously according to the linear, deterministic dynamics, which depends only on the energy properties of the system and how it is coupled to its environment. **(b)** If a measurement is made, then the system *S* instantaneously and randomly jumps to a state where it either determinately has or determinately does not have the property being measured. The probability of each possible post-measurement state is determined by the system's initial state. More specifically, the probability of ending up in a particular final state is equal to the norm squared of the projection of the initial state on the final state.

According to the eigenvalue-eigenstate link (Rule 3) a system would typically neither determinately have nor determinately not have a particular given property. In order to determinately have a particular property the vector representing the state of a system must be on the ray in state space representing the property, and in order to determinately not have the property the state of a system must be in the plane orthogonal to the ray, and most state vectors will be neither parallel nor orthogonal to a given ray. Further, the deterministic dynamics (Rule 4a) typically does nothing to guarantee that a system will either determinately have or determinately not have a particular property when one observes the system to see whether the system has that property. This is why the collapse dynamics (Rule 4b) is needed in the standard formulation of quantum mechanics. It is the collapse dynamics that guarantees that a system will either determinately have or determinately not have a particular property whenever one observes the system to see whether or not it has the property. It is also the collapse dynamics that yields the standard quantum statistical predictions, and these are the predictions that make quantum mechanics such a successful empirical theory. But the linear dynamics (Rule 4A) is also needed to account for quantum mechanical interference effects. So the standard formulation of quantum mechanics has two dynamical laws: the deterministic, continuous, linear Rule 4a describes how a system evolves when it is not being measured and the random, discontinuous, nonlinear Rule 4b describes how a system evolves when it is measured.

While the standard formulation of quantum mechanics has proven remarkably successful in explaining counterintuitive quantum phenomena and in making accurate statistical predictions, the quantum measurement problem threatens the theory with inconsistency. What does it take for an interaction to count as a measurement? Unless we know this, the standard formulation of quantum mechanics is at best incomplete since we do not know when each dynamical law obtains. Moreover, if we suppose that observers and their measuring devices are constructed from simpler systems that each obey the deterministic dynamics, then the composite systems, the observers and their measuring devices, must evolve in a continuous deterministic way, and nothing like the random, discontinuous evolution described by Rule 4b can ever occur. That is, if we suppose that measuring devices are ordinary physical systems interacting in their usual deterministic way (and why wouldn't they be?!), then we get a straightforward logical contradiction between the states predicted by the two dynamical laws.

The problem can be seen by considering a simple experiment where one measures a property *P* that comes in two flavors (*on* and *off*) of a system *S* initially in a superposition of being *on* and being *off*. Let *M* be good a *P* measuring device that starts in a ready-to-make-a-measurement state. Since *M* is a good *P* measuring device, if *S* begins in the on state, *M* would report this at the end of the measurement without disturbing the state of *S*: the state *M* ("ready to measure *S*") **and** *S*(*on*) would evolve to *M*("got the result *on*") **and** *S*(*on*). And if *S* begins in the off state, *M* would report this at the end of the measurement without disturbing the state of *S*: the state *M*("ready to measure *S*") **and** *S*(*off*) would evolve to *M*("got the result *off*") **and** *S*(*off*).

Now suppose that M starts in a ready to make a measurement state and S starts in a symmetric superposition of being *on* and *off*: *M*("ready to measure *S*") **and** [*S*(*on*) + *S*(*off*)]. According to the linear dynamics (rule 4a) the state of the system after the interaction would be a symmetric supposition of a state (i) where *M* gets the result *on* and *S* is *on* and the state where *M* gets the result *off* and S is *off*, [*M*("got the result *on*") **and** S(*on*)] + [*M*("got the result *off*") **and** *S*(*off*)]. But according to the collapse dynamics (rule 4b) the state of the system after the interaction would be either a state (ii) where M gets the result on and S is on, *M*("got the result *on*") **and** S(*on*), or a state (iii) where M gets the result *on* and *S* is *on*, *M*("got the result *off*") **and** *S*(*off*), and for the symmetric initial state, each possibility here is assigned probability equal to one-half. States (i), (ii), and (iii) are mutually incompatible.

In the standard formulation of quantum mechanics it is the collapse dynamics that gets one from a state like (i) where there is no determinate measurement record to one like (ii) or (iii) where there is a determinate measurement record. The problem is that the standard theory does not tell us what constitutes a measurement, so there is no consistent prescription for when to apply the linear dynamics and when to apply the collapse dynamics. And there are always experiments that might at least in principle distinguish between states predicted by the linear dynamics, states like (i), and states predicted by the collapse dynamics, states like (ii) or (iii). Perhaps there is something special about measuring devices, something that causes them to behave in a radically different way from other systems. But until one says exactly what it is that distinguishes measuring devices from other physical systems, one cannot claim to have a complete and consistent physical theory. So the standard formulation of quantum mechanics is logically inconsistent if one supposes that measuring devices are physical systems like any other, and it is incomplete in an empirically significant way if one supposes that they are somehow different.

There is perhaps good reason to suppose that the collapse dynamics is to blame for the measurement problem, and it has always been viewed with some suspicion. As Wolfgang Pauli argued, for a particle initially in a superposition of different locations ``it is not reasonable to invent a causal mechanism according to which `looking' fixes the position'' (Pauli 1971, 222). Pauli concluded that the collapse dynamics cannot describe a real physical process.

Einstein also held the collapse dynamics to be philosophically objectionable, but he also had straightforward physical worries concerning the relationship between the standard formulation of quantum mechanics and relativity. As early as 1927, Einstein complained that the collapse dynamics and the essential use of configuration space to represent the states of entangled systems in quantum mechanics implied, to his mind, `` a contradiction with the postulate of relativity'' (Instituts Solvay 1928, 256). Einstein was certainly right to worry about the compatibility of the standard theory and relativity.

But it is easier to complain about the collapse dynamics than it is to explain how to get by without it. Given the standard interpretation of quantum-mechanical states, which is still held by the overwhelming majority of physicists, it is the collapse dynamics that explains how measurements yield determinate measurement records at all. It is also the collapse dynamics that explains correlations between the results of repeated measurements on a single system. And, more generally, it is the collapse dynamics that provides the statistical predictions that make quantum mechanics an empirically successful theory in the first place.

To be sure, there are alternative formulations of quantum mechanics. Many of these have been cooked up with the specific aim of resolving the quantum measurement problem. Detailed descriptions of these theories can be found elsewhere (see Albert 1992, Bub 1997, Dickson 1998, and Barrett 1999), but there are three features of alternative formulations of quantum mechanics that are worth noting for the philosophical purposes at hand.

First, alternative formulations of quantum mechanics typically suggest radically different metaphysical commitments concerning the nature of the physical world. Explaining exactly how each formulation of quantum mechanics works would take us far afield, but it is worth mention, if only in passing, what the range of ontological options looks like. As we very briefly consider these options, one should keep in mind that while a particular formulation of quantum mechanics typically tends to suggest a particular set of metaphysical commitments and while the metaphysics typically does real explanatory work in each of these formulations of quantum mechanics, there is also typically a range of metaphysical commitments that would be consistent with each formulation.

Some formulations are deterministic (Bohm's theory), others are stochastic (GRW and other collapse theories); some have a rich ontology of physical properties (the standard collapse theory), others explain all phenomena by appeal to the determinate value of a single physical quantity (Bohm's theory, GRW, and some modal theories); some make it impossible to specify diachronic identity conditions for physical objects (the bare theory, DeWitt's splitting worlds theory, and Bell's Everett (?) theory); some require that the physical world be thought of as being constituted by many universes (DeWitt's splitting worlds theory and Barrett's many-threads interpretation of Everett); some suggest that there are typically no simple, determinate matters of fact concerning classical physical properties (the bare theory, relational quantum mechanics, correlations without correlata, and the relative-fact interpretation of Everett); and some seem to require a commitment to a strong form of mind-body dualism (Albert and Loewer's many-minds theory) (See Albert 1992, Barrett 1999, Bell 1987, Bub 1997, Butterfield 1995, Dickson 1998, and Rovelli 1996 for detailed descriptions of these formulations of quantum mechanics and associated metaphysical commitments).

Second, alternative formulations of quantum mechanics provide striking examples of empirical underdetermination. Here we seem to have radically different theories in terms of the fundamental structure of the physical worlds they describe, yet distinguishing the theories from each other from their empirical predictions ranges from being very difficult to being in principle impossible. (While some collapse theories make slightly non-standard empirical predictions (GRW, for example, predicts that one should observe a slight failure in the conservation of energy), many no-collapse theories (like Bohm's theory and Albert and Loewer's many minds theory) are empirically indistinguishable from each other).

Finally, and this is the point that we will turn to next, most alternative formulations of quantum mechanics are, like the standard collapse theory, logically incompatible with the constraints of special relativity. And it is those theories that might most readily be translated into forms that are compatible with relativity (the bare theory, relational quantum mechanics, relative-fact interpretations of Everett, and Albert and Loewer's many-minds theory) that seem to require the most outlandish metaphysical commitments. This has led some philosophers of physics to take seriously the possibility that relativity might be given up as being descriptive of the fundamental spacial-temporal structure of the physical world (Tim Maudlin, David Albert, and Craig Callender are among those who have considered this possibility. See Albert 2000 for a description of various ways that one might understand the relationship between quantum mechanics and relativity and the status of relativity.). But most physicists would presumably be unwilling to entertain giving up relativity.

It is easy to show the incompatibility of the standard collapse formulation of quantum mechanics and special relativity. The incompatibility of most other formulations of quantum mechanics and special relativity can also be shown by closely analogous arguments to the one that follows.

III. Special Relativity and Its Incompatibility with Quantum Mechanics

Following Einstein special relativity is usually presented as two physical principles, the principle of relativity and the principle of the constancy of the speed of light, with a derivation of the Lorentz transformations and a description of some of their physical consequences. [Note #2]

Einstein explained that special relativity is grounded on (1) the principle of relativity: The same physical laws will be valid for all inertial frames of reference, where an inertial frame is frame of reference moving with a constant velocity, and on (2) the principle of the constancy of the speed of light: Light is always propagated in empty space with a definite velocity c which is independent of the state of the emitting body (Einstein 1905).

Einstein then noted that while these principles may at first appear to be mutually contradictory, they can be satisfied if the relationship between coordinate systems in different inertial frames (the unprimed inertial frame and the primed inertial frame moving at velocity v along the x-axis relative to the unprimed frame) is given by the Lorentz transformations. The Lorentz transformations can be thought of as the simplest relations between inertial coordinate systems that would allow each observer to describe a spherically propagating flash of light as a spherical wave propagating at the speed of light from its origin in each observer's own inertial coordinate system. The point of *simplest* here is that the Lorentz transformations do not quite follow from the principle of relativity and the constancy of the speed of light alone, but require a small handful of relatively natural assumptions concerning spatial-temporal uniformity.

There are several immediate consequences of the Lorentz transformations when considered together with standard physical assumptions concerning the nature and relationship between mass, velocity, and energy. The following are almost invariably mentioned in textbook presentations of the special theory of relativity. The mass of a physical object depends on its velocity: the faster an object is moving, the greater its mass. This is closely related to the fact that mass and energy are related to each other by the expression $E=mc^2$. It also follows from the Lorentz transformations that c is a limiting speed for material objects. And it is almost always mentioned in standard presentations of the theory that a rapidly traveling twin would age more slowly than her sedentary brother.

The Lorentz transformations and the principle of relativity directly entail something else concerning the temporal relationships between events that is perhaps less familiar: space-like separated events (events that cannot be signaled between with a pulse of light) have no canonical temporal order. More specifically, if events *A* and *B* are space-like separated, then there will be an inertial frame where an observer would take *A* to occur first and another inertial frame where an observer would take *B* to occur first. And from this it follows, by the principle of relativity, that there can be no physical matter of fact concerning the temporal order of the two events.

That special relativity predicts that there is generally no physical matter of fact concerning the temporal order of events provides a straightforward way of showing the incompatibility of the standard collapse formulation of quantum mechanics and relativity. The incompatibility of alternative formulations of quantum mechanics and special relativity can typically be shown by closely analogous arguments.

Consider an electron e^- and two boxes *E* and *F* equipped with alarm clocks. The clocks are synchronized, the alarm on clock *E* is set to noon on 1 January 2050, and the alarm on clock *F* is set to noon plus one minute on the same date. The electron is put into a superposition of being in each box. An observer Fred then carefully carries box *F* far away from Earth (further than one light-minute away); and another observer Elle carefully positions box *E* near Earth. Fred and Elle are each instructed to look for the electron in their box when the alarm on their clock rings.

Suppose that the initial state of the electron before either observer makes a measurement to locate it (in any inertial frame!) is a symmetric superposition of being on the earth and being far away: e^-(On Earth in box *E*) + e^-(Far away in box *F*).

Now suppose that the standard formulation of quantum mechanics is right and that the collapse dynamics describes the time-evolution of quantum-mechanical states whenever there is a measurement interaction. What is the physical state of the electron when Fred makes his measurement?

Since the measurement events are space-like separated, there will be an inertial frame where Elle makes her measurement first. In this case, Elle's measurement caused a collapse, and the state when Fred makes his measurement is either (i) e^-(On Earth in box *E*) or (ii) e^-(Far away in box *F*). with probability 1/2 in each case.

But since the measurement events are space-like separated, there will also be another inertial frame where Fred is the first to look for the electron. In this case the state of the electron when Fred makes his measurement is the initial state (iii) e^-(On Earth in box *E*) + e^-(Far away in box *F*) since in this inertial frame Elle has not yet interacted with the electron.

The problem is that states (i), (ii), and (iii) here are mutually exclusive. On the standard interpretation of quantum-mechanical states, state (i) describes an electron that is determinately in the box on Earth, state (ii) describes an electron that is determinately in the far-away box, and state (iii) describes an electron that has no determinate position whatsoever. Since the standard formulation of quantum mechanics requires mutually incompatible states for different inertial frames, it is flatly inconsistent with the principle of relativity. So quantum mechanics and special relativity taken together are logically inconsistent.

Since the standard formulation of quantum mechanics had problems even before we considered its relationship with special relativity, a natural reaction would be to blame quantum mechanics for the inconsistency. The problem here presumably lies not with the standard linear quantum dynamics. The linear dynamics can be translated into a form that is compatible with the constraints of relativity in the context of a relativistic quantum field theory. One might consequently naturally suppose that the fault lies with the collapse dynamics.

While one might have thought that the quantum measurement problem would be resolved by finding a satisfactory prescription for when collapses occur, no formulation of mechanics that predicts collapse events like the one described in the story above can be compatible with the constraints imposed by relativity. And one cannot simply give up the collapse dynamics because this is what predicts the standard quantum statistics; and again, that is what makes quantum mechanics worth taking seriously in the first place. Indeed, without the collapse dynamics we lose the standard explanation for how one gets determinate measurement records at all. And even in a relativisitic quantum field theory one should want to be able to explain how we get determinate measurement records distributed with the standard quantum statistics.

One might, of course, try non-standard explanations for how we get determinate measurement records distributed with the standard quantum statistics. One approach is to find a form of the collapse dynamics that is compatible with relativity, but formulations that follow this approach invariably suggests exotic structures for the physical world (see Albert and Aharonov 1981 and Fleming 1996) and are perhaps ultimately still incompatible with the constraints imposed by relativity (Malament 1996). Another approach is to get rid of the collapse dynamics altogether. There are several no-collapse formulations of quantum mechanics around. But most no-collapse theories are also incompatible with relativity, it is extremely difficult to see how fix these up to get compatibility, and the different fixes being considered suggest very different sorts of physical worlds. It is perhaps worth noting also that those no-collapse theories that are most readily made compatible with relativity purchase this virtue at a high price (consider, for examples, the bare theory, Albert and Loewer's many minds theory, relative-fact interpretations of quantum mechanics, and relational quantum mechanics). Indeed, it can be argued that at least some of these theories (the bare theory, relative-fact interpretations of Everett, and relational quantum mechanics) fail to make any empirical predictions whatsoever when taken as descriptions of the physical world Barrett (1999).

The upshot is that a commitment to relativity makes solving the quantum measurement problem all the more difficult and introduces a breadth of ontological possibilities that make it all the more difficult to know what one is claiming when one claims that our current best physical theories are approximately true as a descriptions of the physical world. If wildly different proposals are all taken seriously, it is difficult to take any of them to be in fact approximately true.

IV. Probable Truth and Probable Approximate Truth

Insofar as inconsistent theories cannot be true, we know that the standard collapse formulation of quantum mechanics and special relativity taken together are false.

If our two best physical theories taken together are neither true nor probably true, then perhaps they are probably approximately true. This seems safe enough, but, given the discussion so far, it is not at all clear what it means. The safe optimism here is purchased at the cost of being hopelessly vague.

Part of the puzzle is to explain the sense in which mutually contradictory descriptions of the world might each be approximately true. Of course, a logical contradiction insofar as it is logically false is as far from the truth as possible. Our current best physical theories do not describe any possible world whatsoever, so at least in this sense, they are not even in the ballpark of accurately describing the actual physical world.

Perhaps then our theories are approximately true in the sense that it would take only a minor change in the statement of the theories to get from an inconsistent description of the physical world to a true description. But in the case of quantum mechanics and relativity we have no concrete idea concerning what it means to claim that we are within a minor descriptive change of the truth since we simply do not know what this descriptive change might be.

There is a general point here that can perhaps be made by first distinguishing between forward and backward-looking notions of scientific progress. Insofar as one can specify the content of our current physical theories, one can describe exactly how our current physical theories have succeeded where our past physical theories failed. This does not provide a single, canonical, backward-looking notion of progress; rather, it provides different backward-looking notions of progress for each theoretical virtue one might consider. One might praise Copernican astronomy for giving up the Ptolemaic earth-centered system (which certainly stood in the way of developing a universal mechanics) yet recognize that the empirical predictions of Copernican mechanics were not as accurate as those made by Ptolemaic astronomy. Or one might concede various mechanistic explanatory virtues to Cartesian mechanics over Newtonian mechanics yet recognize the blatantly ad hoc nature of the former theory (especially after attempts to incorporate the successes of Newtonian mechanics into Cartesian mechanics). And it is worth noting that only some of the ways in which one might compare our current best physical theories to their predecessors come in degrees and thus lend themselves to talk of approximation at all. Indeed, it is difficult to assign a nearness-to-the-truth metric to even empirical predictions that can be expressed numerically. Exactly how much closer to the truth is a theory that predicts that neutrons decay with a half-life of about 12 minutes from one that predicts that neutrons are stable? And is this second theory closer to the truth than a theory that correctly predicts neutron decay but falsely predicts that protons decay with a half-life of 1,000,000 years?

Just as there are many backward-looking notions of scientific progress, there are potentially many forward-looking notions of scientific progress. But here we lack any concrete grounds for comparison because we do not know what our future theories will be. While we do have a vague commitment that our future physical theories will somehow be better than our current physical theories, we do not know *how* they will be better. If we did, we would immediately incorporate this insight into our current physical theories. And what makes matters epistemically worse is that, insofar as we expect surprising innovations in the construction of future theories, and we clearly have good inductive reason to expect this, we do not know what the space of possible options for refining our current theories will prove to be. So we do not know even how we might judge our current theories to be mistaken given our better future understanding of the physical world.

In the case of quantum mechanics we know that there are several, apparently quite different, ways that the standard collapse formulation might be descriptively mistaken. This follows from the fact that the alternative strategies for resolving the quantum measurement problem that we understand so far suggest radically different metaphysical commitments. Of course, there may be some way to reach a consensus concerning which options should be ruled out, but we are in fact nowhere near such a consensus. Indeed, if there is any consensus among people who have thought about the quantum measurement problem, it is that none of the options currently on the table are entirely adequate given the constraints imposed by relativity and the virtues we have traditionally wanted from our best physical theories. But if we are dissatisfied with the current options for fixing our two best physical theories, then we do not even know the ways our current theories *might* be taken to be approximately true.

The upshot is that while one might claim that our false physical theories are probably approximately true, given the state of our best current theories, this claim is hopelessly vague, and given the logic of inquiry, it is necessarily so. In order to have any hope of saying anything concrete concerning how our current theories might differ from descriptive truth, one must necessarily figure out how they might be improved, and this can only be done in the context of serious scientific inquiry. If possible at all, concrete judgments of approximate truth can only be made from the perspective of a future generation of physical theories. On this view, the claim that our physical theories are probably approximately true is the claim that we will probably be able to find some sort of descriptive virtue in our current theories from the perspective of our future theories.

This vague notion of approximate truth suggests two closely related notions of vague truth. Our current physical theories might be judged to be true because of the relationship they bear to our less-regimented, commonsense, vague, but true judgments concerning the nature of the physical world, or our current physical theories might themselves be judged to be true but vague.

V. Vague Truth and Approximate Truth

While we know that our most precisely regimented physical theories are false, one might nonetheless hold that empirical science provides us with genuine, albeit vague, knowledge concerning the nature of the physical world. [Note #3] Contrary to appearances, the sun is much bigger than the moon and the earth is roughly spherical. The earth, as Galileo insisted and the Church denied, revolves about the sun and not the other way around. Most of the earth's surface is covered by water. Water is composed of discrete molecules that are themselves composed of two hydrogen atoms attached to one oxygen atom. Hydrogen and oxygen atoms are in turn composed of more fundamental particles. Among these are protons, neutrons, and electrons. Electrons are less massive than either protons or neutrons by a factor of about one thousand. And so on.

Such scientific commonsense is typically taken to be true and for good empirical reasons. But, one might argue, it can be taken to be true only by dint of its being sufficiently vague. Galileo was called before the Inquisition because he held, taught, and defended the claim that “The sun is the center of the world and immovable and that the Earth moves.” [Note #4] If one understands Galileo as making the regimented claim that there is an absolute space with respect to which the sun is stationary and the earth moves, then he is facing the Inquisition for teaching something that is simply false. But in a broader sense, one might want to say that the claim that the sun is fixed and the earth moves is *closer to the truth* than the Church's claim the earth is fixed and the sun moves. But given our current best description and explanations of the motions of the sun and Earth, Galileo would have to have been *closer to the truth* in a way that Galileo himself did not know. One might want to go one step further and claim that Galileo was right and the Church wrong as a piece of scientific commonsense. But in order to understand what Galileo said as the full-stop truth, one must take what he said as being inherently vague in a sense that Galileo himself would not have been able to explain. One might understand the claim that Galileo's position was true as the claim that what Galileo said can more readily be translated into a true descriptive claim by the lights of a future regimented theory than the official position of the Church.

Our best physical theories might be understood as being approximately true insofar as they are refinements of scientific commonsense or if one understands our them as a part of scientific commonsense, in which case they might be considered to be vaguely true in a sense that can only be explicated from the perspective of yet unknown future regimented theories. The commitment to the truth of our best theories in the first sense is grounded in the commitment to the truth of the commonsense that one's physical theories are taken to regiment. Any failure in the description of the physical world provided by the regimented theories must be an artifact of their increased descriptive precision. And it is for this reason that they can be taken to be vaguely true, but in a sense that one cannot now explain. The commitment to the truth of our best theories in the second sense is purchased at the price of acknowledging that they are vague enough that they might prove to be translatable as truths, in ways that we do not yet understand, in our best future regimented physical theories, which we do not yet have. There is a Popperian-flavored tradeoff here: if we understand our best theories as regimented description of the physical world, then, insofar as anything is certain, they are certainly false; but if we understand them as a piece with scientific commonsense, then while they may well be taken to be true, but it is unclear what sort of world they are supposed to describe.

There is perhaps evidence for this sort of regimentation-risk model of our physical knowledge in the reactions of physicists to the quantum measurement problem and the incompatibility of quantum mechanics and special relativity we have been discussing. Perhaps the most common reaction is to insist that while *quantum mechanics* is true, the standard collapse formulation of quantum mechanics is not. But what exactly does the *quantum mechanics* that is supposed to be true tell us about the physical world? Since we do not have a satisfactory regimentation of quantum mechanics at hand, either one or more of the formulations or the principles that have been used to construct these formulations is being taken as vaguely true or the descriptively true *quantum mechanics* is some refinement of one or more of our current best formulations of quantum mechanics (a theory that we do not yet have).

On this understanding, one might naturally take our physical knowledge to reside not in our best regimented physical theories understood as descriptive of the physical world but in scientific commonsense. Some aspects of scientific commonsense are what our best regimented theories are supposed to refine and explicate. And these theories are themselves supposed to be refined by our future, better theories. We want our future theories to explain the senses in which our past theories could be taken to be approximately or vaguely true; but, just as important, we want our future theories to explain the remarkable successes of our past theories when they were at best only approximately or vaguely true.

The relationship between approximate truth earlier and the two notions of vague truth here is obvious. It is for precisely the same reason that we do not know how our current physical theories might be taken to be approximately true that we do not know how they succeed in being vaguely true from the perspective of future descriptions of the world. And just as one cannot know which features of our current regimented physical theories will be preserved in our future best descriptions of the world, one cannot know precisely where in the regimentation of our vague scientific commonsense descriptive errors were introduced. In either case, as we found with approximate truth, one's only chance at explicating vague truth is to begin to construct the next generation of physical theories.

Further empirical inquiry will presumably provide us with firm future commitments concerning the descriptive virtues and vices of our current theories. The successes and failures of our current regimented theories can be expected to influence our future scientific commonsense, which we will in turn seek to clarify and sharpen through future regimentation.

A natural objection to this account of scientific knowledge is that there is no concrete description of how our current theories are approximately true or the sense in which they can be taken to be vague; rather, on this account both the notions of approximate truth and vague truth to which one appeals are themselves hopelessly vague. This is perhaps an unfortunate feature of this account of scientific knowledge; but, if I am right, this is a necessary feature of any account of any account our scientific knowledge given that we in fact do not even know how our current physical theories might be approximately of vaguely true. More work needs to be done to have a philosophically satisfactory notion of approximate truth or vague truth for our current physical theories, but it is not abstract philosophical work that needs to be done. The only way to get clear about even how our best physical theories might be taken to be approximately true is to get clear about the range of options we have for the construction of the next generation of physical theories. And this is a piece with physics.

VI. Epistemic Moral

We have good reason to suppose that our best physical theories, quantum mechanics and special relativity, considered together, are false. Since we do not now know how we will fix them, we do not know how they are or might be approximately true as descriptions of the physical world. Neither understanding the approximate truth of our current best physical theories as residing in their unspecified similarity to our future regimented theories nor understanding our best theories as regimented commonsense nor understanding our best theories as being themselves vaguely true provide us with anything useful to say about how or where our best physical theories fail to describe the physical world. Indeed, the only recourse in clarifying the claim that our best current physical theories are approximately true or vaguely true is to find theories that we take to be better descriptions of the world against which we can judge the merits of our current theories. If this is right, then explaining the precise content of our epistemic commitment to our best physical theories is, if possible, a task for ongoing empirical inquiry not for traditional epistemology.

NOTES

1. This paper started as a talk I gave at UC San Diego in Fall 2001. I later presented the first part of the argument at the PSA 2002 Meetings in Milwaukee Wisconsin. I would like to thank Kyle Stanford, David Malament, Pen Maddy, Rob Clifton, Craig Callender, Michael Dickson and Martha Barrett for many discussions and for helpful suggestions on earlier versions of this paper.

2. See Maudlin 2002 for a discussion of what relativity involves and more details concerning the relationship between relativity and quantum mechanics.

3. The notion of degrees of regimentation and the closely related notion of degrees of abstraction are commonplace in the philosophy of science. See Nancy Cartwright (1999) and Patrick Suppes (2002) for a recent examples of ways one might characterize these. There is, however, good reason to believe that there is no canonical characterization of degrees of abstraction or of degrees of regimentation. If there were, then there might well be canonical notions of approximate or vague truth. But it is not just that there is no canonical characterization of degrees of abstraction or regimentation. Part of the argument here is that there is good reason to believe that we do not yet have a characterization of degrees of abstraction or regimentation that will in the future be judged to be most relevant to the claim that our current best physical theories are approximately or vague true as descriptions of the physical world.

4. See de Santillana (1955, 223) for the charges against Galileo. See Galileo's *Letter to the Grand Duchess Christina* in Drake ed. (1957) for an example of his defense of his position.

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