**Quantum Mechanics and its (Dis)Contents**

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**Abstract**

Recently, Richard Healey and Simon Friederich have each advocated a pragmatist interpretation of quantum mechanics as a way to dissolve its foundational problems. The idea is that if we concentrate on the way quantum claims are used, the foundational problems of quantum mechanics cannot be formulated, and so do not require solution. Their central contention is that the content of quantum claims differs from the content of non-quantum claims, in that the former is prescriptive whereas the latter is descriptive. Healey also argues that claims about non-decoherent systems are largely devoid of content. I consider various objections to these claims, noting in particular the ways in which the application of pragmatism to quantum mechanics differs from previous examples of pragmatist therapy. I conclude that a pragmatist dissolution of the foundational difficulties of quantum mechanics is promising, but requires fairly radical changes to our understanding of the content of propositions and the extent of physical explanation.

**1. The Pragmatist Project**

One standard way of illustrating the problematic nature of quantum mechanics goes like this. The quantum state plays the same role in quantum mechanics as the particle distribution does in classical physics—as a representation of physical state of the system under study. For example, the spin of an electron might be represented by the state $2^{-\frac{1}{2}}(|\left.\uparrow \right⟩+|\left.\downright \right⟩)$, where $|\left.\uparrow \right⟩$ represents a spin-up electron and $|\left.\downright \right⟩$ represents a spin-down electron (relative to some axis). If a spin measurement along this axis is performed on the electron, the Born rule says there is a 50% chance of getting the result “spin-up” and a 50% chance of getting “spin-down”. But the standard dynamical law of quantum mechanics—the Schrödinger equation—entails that the post-measurement state is $2^{-\frac{1}{2}}(|\left.U\right⟩|\left.\uparrow \right⟩+|\left.D\right⟩|\left.\downright \right⟩)$, where $|\left.U\right⟩$ represents a measuring device reading “spin-up” and $|\left.D\right⟩$ represents a measuring device reading spin-down. This state is entirely symmetric between the spin-up result and the spin-down result. So when the result is spin-up, what in the physical state of the system makes it the case that the result is spin-up? Quantum mechanics doesn’t say. So it looks like quantum mechanics is either not right, or it is incomplete.

 Various strategies have been proposed for solving this problem—the *measurement problem*. Bohmians propose to complete quantum mechanics by adding *particle locations* to the representation, where the particles are either associated with the $|\left.U\right⟩|\left.\uparrow \right⟩$ term or the $|\left.D\right⟩|\left.\downright \right⟩$ term in the state (Bohm 1952). Spontaneous collapse theorists propose to change the dynamics by which the state evolves, so that the measurement process precipitates a “collapse” to one term in the state, where the other term (essentially) disappears (Ghirardi, Rimini and Weber 1986). Everettians propose that both terms remain, and that an observer should be represented like the measuring device above, with one component in each term of the sum (Everett 1957). That is, the observer splits into two, with one successor seeing “spin-up” and one successor seeing “spin-down” (Wallace 2003).

 All these approaches have their difficulties. The dynamics governing the Bohmian particles and the dynamics of the spontaneous collapse mechanism are both non-local, in prima facie conflict with special relativity. The Everettian approach doesn’t add new dynamics, and the dynamics of standard quantum mechanics can arguably be made consistent with special relativity, so this difficulty doesn’t arise. Nevertheless, the branching observers of the Everettian approach stretch our credulity, and also present difficulties for understanding probability, since every outcome of a measurement is observed by one or other of my successors. These problems (and others) have been addressed at great length, but the foundations of quantum mechanics remain hotly contested territory.

 Despite this, quantum mechanics is arguably the most empirically successful theory ever devised. How can it be so successful, given that we don’t understand what it says? A reasonable suspicion is that the success of the theory is evidence that we *do* understand what it says. That is, if we focus on how quantum mechanics is actually *used* by physicists, we will find that there are no genuine foundational problems.

 This is the promise of a pragmatist dissolution of the measurement problems pursued separately by Richard Healey (2012, 2015, 2017) and Simon Friederich (2015). Their philosophical inspirations are somewhat different—Healey takes his motivation from the American pragmatists and Robert Brandom, whereas Friederich sees his approach as Wittgensteinian. But the details of their dissolution of the measurement problem are very similar. They each suggest that if we understand the meaning of quantum mechanical claims in terms of their *use*, then we can see that quantum mechanical claims function very differently from “ordinary” non-quantum mechanical claims. Further, they argue that this difference is such that the measurement problems as outlined above cannot even be formulated.

 I shall not take issue with the pragmatist account of meaning, in either its Brandomian or Wittgensteinian variant. Nor do I insist on a realist understanding of quantum mechanics in a way that would beg the question against pragmatism. Rather, my argument here is that a pragmatist understanding of *quantum mechanics* raises its own special difficulties, ones that do not arise in other pragmatist dissolutions of ontological problems.

**2. The Pragmatist Framework**

What are the distinctive features of a pragmatist understanding of quantum mechanics? A key ingredient is Healey’s distinction between two kinds of claim: quantum claims and non-quantum magnitude claims. Quantum claims “concern a quantum state, quantum probability (or expectation value), or other model element introduced by quantum theory” (Healey 2015, 11). Non-quantum magnitude claims are characterized negatively—as claims concerning the magnitude of some physical quantity that do *not* involve quantum states, quantum probabilities etc. So for example, “The total squared-amplitude of quantum state *ψ* in region *R* is 0.9” is a quantum claim, but “The particle is located in region *R*” is a non-quantum magnitude claim.

 Healey bases this distinction on a difference in the way the two kinds of claim are used: quantum claims are not used to describe or represent physical systems, but non-quantum magnitude claims are so used. Instead of describing, the role of a quantum claim is to license a user of quantum theory to express non-quantum magnitude claims and to warrant the user to adopt appropriate epistemic attitudes toward these claims (Healey 2015, 11). Returning to the example, in circumstances in which it is appropriate to use state *ψ* to guide our beliefs about a particular particle, the fact that its squared amplitude in region *R* is 0.9 licenses an appropriately situated observer in believing to degree 0.9 that the particle is in region *R*.

Figure 1: The apparatus of Juffmann et al. (2009)

 Friederich endorses Healey’s distinction between quantum and non-quantum claims (2015, 75). Friederich, too, takes non-quantum claims to be descriptive and quantum claims to be non-descriptive (2015, 114). In particular, he takes the role of quantum claims to be epistemic, in the sense that they prescribe the rational degree of credence in non-quantum claims (2015, 84). Hence there is broad agreement between Healey and Friederich concerning the central framework at the heart of a pragmatist understanding of quantum mechanics.

 Healey (2012; 2015) also introduces a helpful example to illustrate the pragmatist approach: the demonstration of single-particle interference for C60 molecules by Juffmann et al. (2009). The apparatus is shown schematically in Figure 1. A beam of C60 molecules with well-defined velocity is produced (top left) and passes through two gratings of a Talbot-Lau interferometer in a high vacuum (top right). The molecules are deposited on a silicon surface, which is later moved into a second high-vacuum chamber and scanned with a scanning tunneling electron microscope (bottom right). The result is an image of a thousand or so individual C60 molecules forming an interference pattern (bottom left).

 Juffmann et al. use a plane wave as the quantum state of an incoming C60 molecule. They then apply the Schrödinger equation to obtain the time evolution of the quantum state through the apparatus. In particular, the interaction between the state and the gratings produces a state with multiple terms, and these terms interfere to the right of the gratings to produce a state at the silicon surface exhibiting the characteristic pattern of high-amplitude and low-amplitude bands.

 A suitably situated agent—one who is in a position to observe the image generated by the electron microscope—can use this final state as a guide to what to believe. In particular, she can use the Born rule to generate the probability that a C60 molecule will be located in a particular region of the silicon surface. That is, the quantum state prescribes how this agent should ascribe credences to non-quantum magnitude claims of the form “The C60 molecule is located in region R”. The Born rule thus entails that her credences in claims of this form should be higher for some regions than for others. Hence quantum mechanics explains interference, not in the sense that the quantum state describes a real entity, but in the sense that it tells the agent to *expect* interference effects.

 Decoherence plays an important role in this explanatory story (Healey 2015, 13). When the C60 molecule adheres to the silicon surface, it interacts with the surface in complicated ways. This has the result that the state of the C60 molecule undergoes environmental decoherence: the state diagonalizes when written in the position basis, meaning that off-diagonal terms in the state—interference terms—become very small. That is, although there is interference prior to the molecule adhering to the surface, after it has adhered, further interference effects are essentially ruled out. And this in turn warrants the applicability of the Born rule to the quantum state: when the state is approximately diagonal in the position basis, then the Born rule can be used to ascribe probabilities to non-quantum magnitude claims concerning the molecule’s position. Friederich concurs with this role for decoherence (2015, 77).

 The key feature of the Healey-Friederich approach is that quantum claims do not *describe* physical systems, but instead *prescribe* degrees of belief in non-quantum claims (taken as descriptive). Since it is a presupposition of the foundational problems of quantum mechanics that the quantum state is descriptive, adopting the pragmatist framework *dissolves* these problems; there is no need for a solution. If the quantum state is not a description at all, it cannot be an *incomplete* description. And there is no conflict between a *prescriptive* quantum state that is spread out over a number of different experimental outcomes and a *description* that one of these outcomes actually occurs.

The Healey-Friederich approach naturally invites accusations of instrumentalism: at first glance, it looks like quantum mechanics is treated purely as a predictive instrument. They are sensitive to these accusations, each noting that their approach, unlike instrumentalist or constructive empiricist approaches, does not restrict either meaning or belief to claims about the observable world (Healey 2017, 253; Friederich 2015, 114). Note, for example, that the electron microscope plays no essential role in Healey’s analysis of C60 interference: the position of the microscopic C60 molecule can be truly described by a non-quantum magnitude claim whether it is imaged by a microscope or not. As long as the state decoheres to a suitable extent, then a claim about the position of the C60 molecule has content, and a suitably situated agent should believe the claim to the extent prescribed by the Born rule.

 However, there is an important sense in which Healey-Friederich pragmatism is similar to instrumentalism, and distinct from constructive empiricism: Healey and Friederich seek to dissolve our foundational worries about quantum mechanics by denying that quantum states have descriptive content. We shouldn’t worry that the quantum state of the C60 molecule at the point of measurement is a superposition of terms representing distinct positions, because careful attention to the way quantum mechanics is used shows us that the quantum state isn’t used to *represent* the C60 molecule at all. Constructive empiricism, on the other hand, enjoins us to take quantum claims (and all other theoretical claims) as literally descriptive, even if we shouldn’t (all things considered) actually *believe* those claims (van Fraassen 1980, 11). Hence constructive empiricism, even if successful, does not dissolve the measurement problem; this is why van Fraassen (1991) felt compelled to offer a *solution*.

Healey and Friederich also both insist that quantum state ascriptions, and the degrees of belief they prescribe, should be regarded as *relative* to a physical situation. This feature of quantum claims is designed to dissolve the apparent non-locality of quantum mechanics. To see why non-locality is a potential problem, consider a pair of electrons in the spin singlet state$ 2^{-\frac{1}{2}}(|\left.\uparrow \right⟩\_{1}|\left.\downright \right⟩\_{2}+|\left.\downright \right⟩\_{1}|\left.\uparrow \right⟩\_{2})$. A z-spin measurement on either electron produces either a spin-up outcome or a spin-down outcome with probabilities of 1/2 each. But a z-spin measurement on one electron allows us to predict with certainty the outcome of a z-spin measurement on the other, no matter how far apart the electrons are. This might lead you to say that the spin measurement on the first electron affects the physical state of the other—and in fact this is just what Bohm’s theory and spontaneous collapse theories do say. But any such influence, to be effective, would have to be instantaneous, and instantaneous space-like influences are apparently ruled out by special relativity.

Healey and Friederich each respond that since quantum states aren’t used to describe the physical world, there is no need for agents physically situated by the two electrons to use the same quantum state to prescribe their degrees of belief (Healey 2012, 754; Friederich 2015, 60). When a z-spin measurement is performed on one electron, the state decoheres, and the Born rule entails that the agent performing the measurement should ascribe equal degrees of belief to the two outcomes. When this agent learns that the outcome was z-spin up, it is appropriate for her to also fully believe that the other electron is z-spin down. That is, if she were to travel to the location of the other electron, she should fully expect a z-spin measurement on it to yield z-spin down. But the agent who is already stationed by the other electron should continue to use the singlet state to prescribe her degrees of belief: if her electron is measured, she should expect z-spin up and z-spin down with credences of 1/2 each.

**3. Content**

There are at least two questions one can raise concerning this pragmatist understanding of quantum mechanics. The first concerns motivation: *Why* should we conceive of quantum states as Healey and Friederich suggest, rather than as descriptive of physical systems? The second concerns adequacy: Does the pragmatist conception of quantum states *succeed* in dissolving our worries about the foundations of quantum mechanics? Obviously these two questions are related: success in dissolving the foundational problems of quantum mechanics would be a powerful motivation for accepting a pragmatist approach! But nevertheless, they can be addressed somewhat separately, insofar as there are general reasons to favor a pragmatist understanding of the scientific enterprise. That is, one can ask whether pragmatism does in fact yield the understanding of quantum mechanics that Healey and Friederich endorse, and *then* one can go on to consider whether this understanding helps us with the foundational problems of quantum mechanics. That is the order I will follow here.

 At one level the pragmatist position is quite easy to motivate. In any application of quantum mechanics to a system, empirical predictions are generated by the Born rule. That is, the role of the quantum state is ultimately to ascribe probabilities to observed outcomes, and it is quite plausible to regard these probabilities as prescribing the credences a suitably situated agent should have in each of these outcomes. The outcomes themselves are not expressed in terms of quantum states at all, but in terms that, in general, conform well to Healey’s characterization of non-quantum magnitude claims. So quantum states are used to prescribe the proper credences in non-quantum magnitude claims, and non-quantum magnitude claims are used to describe the world.

 By itself, though, this kind of motivation doesn’t get us particularly far. Advocates of realist views of the quantum state—Bohmians, Everettians and collapse-theorists—accept that quantum mechanics generates its predictions in probabilistic terms, but deny that this tells us that quantum state ascriptions are *purely* prescriptive. After all, a descriptive claim can generate a probabilistic inference: from “Atmospheric pressure over New England is high” I can infer that the probability of rain in Vermont is low. So similarly, a Bohmian will claim that from a quantum state we can infer the probabilities of various measurement outcomes, in this case because the quantum state, though descriptive, is an *incomplete* description of the system under study.

Furthermore, it would be naïve to expect a direct motivation for the pragmatist framework in terms of the actual use of quantum and non-quantum claims by physicists. A general feature of pragmatism is the foregrounding of the variety of roles of human discourse, and the rejection of the assumption that the only role of a declarative statement is description or representation (Friederich 2015, 51). It is typical of pragmatist accounts that superficially descriptive claims are argued to have some other function. So, for example, expressivism about moral values can be seen as a kind of pragmatism (Price 2011, 9): claims about moral values look superficially descriptive, but instead, it is argued, they function to express approval or disapproval. So the fact that physicists use quantum claims in apparently descriptive ways does not provide direct evidence against the pragmatist assertion that these claims in fact function to prescribe our degrees of belief in non-quantum claims.

 Juffmann et al. (2009), for example, use quantum and non-quantum claims in prima facie descriptive ways prior to decoherence. They describe the “quantum wave features” of the C60 molecules that account for the interference phenomena, and also the “composite particle nature of individual molecules” that accounts for the deposition of the molecules imaged on the silicon surface (2009, 1). That is, at times they use quantum claims in ways that might be taken as describing the passage of a wave through the apparatus, and at times they use non-quantum claims in ways that might be taken as describing the passage of a particle through the apparatus. But a pragmatist will warn against the automatic assumption that such claims really are descriptive.

 Hence neither Healey nor Friederich motivate their accounts directly from the actual usage of physicists. Indeed, Friederich provides no direct motivation for his account, relying on its ability to dissolve quantum paradoxes as motivation enough (2015, 6). Healey, on the other hand, bases his account on a general pragmatist theory of propositional content. He thinks we can interpret the usage of physicists in a way that is consistent with this theory of content. That is, the theory of content tells us what we should say and what we should refrain from saying, and physicists’ actual usage conforms to a large extent to these norms.

So let us turn to Healey’s account of propositional content. Healey adopts an inferentialist account of meaning, in the spirit of Brandom (1994; 2000). That is, the meaning of a claim lies in the material inferences it supports, rather than in direct representation of reality. The claim “There is a bat in the barn” derives its meaning from the material inferences I can draw from it, for example “There are droppings on the barn floor”, or “Something flies around the barn when I turn on the light”. It does not derive its meaning from correspondence between words and world.

 How does that apply to quantum mechanics? Consider a non-quantum magnitude claim ascribing a location to a particular C60 molecule. When the molecule has adhered to the silicon surface, a claim of this kind licenses plenty of inferences, for example “The electron microscope forms an image of the molecule at this location”. Hence it has content, and it is worth asserting.

 But what about earlier on? Suppose I assert that a C60 molecule is close to the first diffraction grating. Healey thinks that such an assertion licenses erroneous inferences. In particular, if the molecule has a precise location close to the diffraction grating, then it passes through exactly one slit in the grating, and if it passes though exactly one slit, then no interference pattern is possible (2012, 745).

 Of course, material inference is not deductive inference. For one thing, it is non-monotonic: addition of extra premises can undercut the inference. I can’t infer “Something flies around the barn when I turn on the light” from “There is a bat in the barn” given the additional premise that the bat is dead. So similarly, perhaps the moral is that I can’t infer “There is no interference pattern” from “The molecule is close to the diffraction grating” given *quantum mechanics* as an extra premise.

 Healey’s response is that this is correct, but then in the pre-decoherence context the claim about the location of the molecule has so little content that maybe one shouldn’t assert it at all. It would be a mistake to infer the absence of interference, given quantum mechanics. But by the same token, it would be a mistake to infer that it passes through the first slit, or the second slit, or any other particular slit. It would be a mistake to infer that is passes through no slit at all, because then we might further infer that it doesn’t arrive at the silicon surface. It would be a mistake to infer that it passes through all the slits, because then we might further infer that it arrives at the silicon surface at multiple locations at once. Since pretty much any inference one might draw from the non-quantum magnitude claim would be erroneous, the claim is almost contentless, and hence not worth asserting. If I assert that a molecule is close to the first diffraction grating, then those who do not recognize this lack of content might be misled into making one of the above inferences, and those who do recognize the lack of content will not have learned anything much.

 What about quantum claims? Claims about the quantum state of a system license different inferences from non-quantum claims. In particular, from a quantum claim one can only infer the *probability* of some non-quantum magnitude claim, via the Born rule. Healey takes Born probabilities to prescribe the appropriate degree of belief in the relevant non-quantum claims; hence quantum claims are *prescriptive* rather than descriptive.

 Beyond this difference, though, it looks like similar considerations should apply to quantum claims as to non-quantum claims. Quantum claims prescribe degrees of belief in non-quantum claims via the Born rule, and the Born rule is only applicable in decoherent contexts. This is arguably a consequence of no-go theorems like Kochen and Specker (1967): since not all quantum observables can consistently be assigned simultaneous values distributed in accordance with the Born rule, and given that there is no way to privilege some observables over others, we should refrain from drawing any probabilistic inferences from a quantum claim prior to decoherence. Decoherence picks out a preferred basis: it provides a way to privilege one set of observables, and guarantees that the application of the Born rule for those observables does not generate any inconsistency (Healey 2012, 749).

 It apparently follows from this that the quantum state at the silicon surface has prescriptive content, but the earlier quantum state, say just before the diffraction grating, has very little prescriptive content concerning the system at that time, because the Born rule is inapplicable at that time. This is consistent with the lack of descriptive content of non-quantum claims about the C60 molecule at that time.

 As noted earlier, Friederich does not adopt Healey’s inferential account of propositional content. Instead, he wishes to leave open the possibility that non-quantum magnitude claims have well-defined descriptive content prior to decoherence (2015, 79). Nevertheless, he does agree with Healey that decoherence is a precondition for applying the Born rule, not because the non-quantum claims to which the Born rule ascribes probabilities have no content prior to decoherence, but simply because the Born rule is unreliable when applied to such claims (2015, 79). Hence it looks like Friederich, too, must say that quantum claims lack prescriptive content prior to decoherence.

**4. Concerns About Content**

Healey’s motivation for the pragmatist framework lies in his inferentialist account of content. How successful is this motivation? I will raise two initial worries, neither of which I think is ultimately fatal to the project. I will then consider whether Friederich’s position on content is an improvement over Healey’s.

The first worry, and perhaps the most obvious, concerns the distinction between the prescriptive content of quantum claims and the descriptive content of non-quantum magnitude claims. Consider again the claim that there is a bat in the barn. This claim is descriptive, if anything is. It licenses an inference to “There are droppings on the barn floor”. But that doesn’t mean you should be *certain* that there are droppings on the barn floor. Presumably the background assumptions operative in this material inference suggest a certain (roughly specified) *degree* of belief. That is, the claim that there is a bat in the barn *prescribes* degrees of belief in various further claims; this is what its inferential content consists in.

 The worry, then, is that the distinction between the prescriptive content of quantum claims and the descriptive content of non-quantum claims is not supported by the inferentialist account of content. According to inferentialism, no claims are descriptive if description requires representation. The content of every claim lies in its licensing of inferences, where an inference is just the prescription of a degree of belief in some further claim. All that distinguishes quantum claims from non-quantum claims, then, is that the prescription of degrees of belief is mediated by quantum mechanics, and hence calculated via the Born rule.

 Perhaps this is all to the good, though. The main point that Healey seeks to establish is that quantum claims are prescriptive rather than descriptive, so if no claims are descriptive, Healey’s point goes without saying. But on the other hand, I don’t think Healey takes his point about quantum claims to be trivial in this way; his point is to *contrast* the way quantum claims are used with the way non-quantum magnitude claims are used. And there may well be various pragmatist tools to do just that. After all, one of the key tenets of pragmatism is to pay attention to the diversity of functions that our claims fulfill, not to reduce those functions to a single function, such as prescribing credences. Contemporary pragmatists typically acknowledge a sense in which many claims can be said to represent or describe, although not in the sense of standing in a traditional word-world relation (Brandom 1994, 76). For example, Healey might appeal to Price’s (2011, 20) distinction between i-representation and e-representation: our assertions are i-representational in that they have inferential content, but a subset of them are also e-representational that the content is answerable to the environment via notions such as tracking and covariance. Using such a distinction, one might make the case that non-quantum claims are used to represent in ways that quantum claims are not, while denying that *any* claim represents the world in a straightforward *picturing* sense.

 A second worry about content concerns the lack of content of claims about non-decoherent quantum systems. The general form of the worry is that Healey’s position on content fails to adequately take into account the role of conditional or counterfactual inferences. Much of the content of our ordinary “descriptive” claims has this conditional or counterfactual nature. For example, the content of “There is a bat in the barn” includes a great deal of content that could be thought of as counterfactual: from “There is a bat in the barn” I can infer “If I were to turn on the light, I would see something flying around.”

 Now consider the prescriptive content of the quantum state of the C60 molecule as it passes through the Juffmann apparatus. Prior to decoherence, the state prescribes no credences to non-quantum claims, and to this extent is devoid of content. But nevertheless, it *would* ascribe credences to various non-quantum claims given a suitable intervention on the system. If the diffraction grating were replaced by a screen, decoherence at the screen would allow the prescription of a probability (close to 1) to “The molecule hits the screen.” If detectors were placed behind each slit, then decoherence at the detectors would allow the prescription of a (low) probability to “The particle is located behind the leftmost slit.” Hence if counterfactuals contribute to content (and it is hard to see why they should not), then quantum claims have a good deal of content even prior to decoherence.

 The same goes for non-quantum magnitude claims, and for the same reason: if from a quantum claim I can infer a particular credence in a non-quantum claim, then that non-quantum claim thereby acquires content. So even prior to decoherence, the claim that the C60 molecule approaches the diffraction grating has content, in that were the grating replaced by a detector, the Born rule would prescribe a credence in the claim. Similarly, the claim that the C60 molecule passes through the leftmost slit has content, in that were there a detector behind each slit, the Born rule would prescribe a credence in the claim.

 It is worth noting, though, that the pragmatist project doesn’t stand or fall with the denial of content to claims about systems prior to decoherence. It is possible to accept Healey’s assertion that quantum claims function differently from non-quantum claims, while denying what he says about the content of such claims prior to decoherence. That is, one might accept that “The C60 molecule passes through the leftmost slit” has content, and that a quantum claim about the state at the grating has content, where the latter prescribes the appropriate degree of belief in the former. The role of quantum mechanics, on such a view, is to make sure that our material inferences based on the content of the non-quantum claims do not land us in trouble. That is, while one might be tempted, based on classical intuitions, to conclude that if the particle passes through a determinate slit, then there is no interference, quantum mechanics blocks such an inference.

 Understood in this way, the quantum state prior to decoherence has rich counterfactual content, prescribing credences in a wide variety of non-quantum claims. By the same token, those non-quantum claims have content. But because of the counterfactual nature of the relevant inferences, no contradictions result. If one were to put a detector behind the leftmost slit, there is a (small) probability a C60 molecule would be found there, but if there is no detector, the deposition of molecules on the silicon surface generates an interference pattern. However, even though the quantum state has rich content prior to decoherence, it would be a mistake to regard the quantum state as giving us a *picture* of the system in any sense.

 On this view, the role of decoherence is not, as Healey argues, to delimit the range over which our claims have content, but to delimit the range over which our material inferences can draw unproblematically on our classical intuitions. The basic structure of the pragmatist approach remains intact: quantum claims are prescriptive rather than descriptive, and since the function of quantum claims isn’t to describe physical systems, the measurement problem does not arise.

 Friederich, recall, is not committed to the lack of content of non-quantum claims prior to decoherence, and indeed explicitly explores the possibility that all observables have sharp values at all times, via which the content of the corresponding non-quantum claims can be specified (2015, 162). However, Friederich notes that this proposal “goes beyond the boundaries of the therapeutic approach” (2015, 157). If the goal of the therapeutic (or pragmatic) approach is to dissolve the worry that quantum mechanics is either not right or incomplete, then Friederich’s proposal threatens to reintroduce the latter worry: quantum mechanics says nothing about these sharp values, and hence is incomplete. His therapeutic ends would be better served, perhaps, by adopting Healey’s inferentialism, modified along the lines just sketched.

**5. Time and Explanation**

If the above is correct, then despite worries about the details of Healey’s and Friederich’s respective accounts of content, the pragmatist can give a good account of the predictive success of quantum mechanics, and one that is not at odds with the foundational problems of the theory, since those problems cannot even be formulated under a pragmatist understanding of the quantum state.

 Nevertheless, some may feel that even if the pragmatist account gives us a good understanding of how quantum mechanics is used to *predict*, it does not thereby give us a good understanding of how quantum mechanics is used to *explain*. That is, some may feel that the predictive success of quantum mechanics was never in question, and that the pragmatist account really just dodges the real problems of quantum mechanics, which lie in its inability to provide adequate explanations of the phenomena it so accurately predicts.

 Such objections to the pragmatist project have to be couched carefully though. Realist objections against the pragmatist approach are liable to beg the question. The realist may object that the pragmatist fails to give an explanation for interference, for example, because the pragmatist doesn’t give a mechanistic account of the formation of the interference pattern analogous to the classical explanation of interference in light or water waves. But the pragmatist will reply that since the role of the quantum state is to prescribe, not describe, the call for a mechanism amounts to nothing more than the flat denial of the pragmatist account of the function of quantum claims. Furthermore, Healey argues at length that pragmatist accounts of phenomena like interference fulfill two requirements of good scientific explanation: “(i) they show that the phenomenon to be explained was to be expected, and (ii) they say what it depends on” (2015, 4). Friederich concurs with this assessment (2015, 116). Nevertheless, I think there is something to the suggestion that pragmatism about quantum mechanics renders explanation problematic. In this section I will try to diagnose a sense in which the pragmatist approach seems to fall short in terms of explanation, in a way that does not simply amount to a flat denial of the pragmatist approach.

 To do so, it will be helpful to contrast the pragmatist approach to quantum mechanics with pragmatist approaches to other issues, such as the status of the mental, the mathematical, or the moral. Here, too, the pragmatist tries to dissolve foundational problems by arguing that apparently descriptive claims in fact have some other function. When we say “Kicking your sister is bad,” we appear to be ascribing a property, badness, to physical acts of a certain sort. But we can examine the physical act as closely as we like and fail to find the *badness*. Here the pragmatist responds that to say that kicking your sister is bad is not to *describe* the act as having a certain property, but to *express* our disapproval of such acts.

 Note, though, that the pragmatist account of the function of moral claims does nothing to restrict the ordinary physical claims we make about bodily actions—what a kick is, physiologically speaking, and how it is caused. It is certainly not the case that in applying a moral evaluation to a kicking action we are thereby precluded from explaining it in physiological terms. Indeed, since the function of the moral evaluation is distinct from that of physiological description, it is hard to see how the former could restrict the latter.

This is where the pragmatist account of quantum discourse deviates from standard pragmatist analyses—because applying a quantum claim to a physical system *does* preclude certain sorts of ordinary physical explanation. Consider the Juffmann interference experiment again. We explain interference via a three-step temporal process. First, we describe the preparation of the system. Given this preparation, a certain quantum state is appropriate—in this case, a plane wave that evolves into a set of overlapping arc-shaped wave fronts. This quantum state in turn prescribes degrees of belief for the various locations at which the C60 molecule might be located on the silicon surface. But note here that in the middle stage—the stage at which one uses a non-decoherent quantum state—non-quantum descriptions of the location of the molecule are to some extent blocked. According to Healey, such claims have almost no content, and so are not worth asserting. In the previous section I urged that we should regard such claims as having content—but nevertheless, many of the standard inferences from these location claims are blocked, so on an inferentialist account of meaning, they have significantly different content from ordinary location claims. So the applicability of a non-decoherent quantum state to a system precludes, or at least limits, our ability to describe that system in ordinary non-quantum terms.

 There are two senses in which this distinctive feature of the application of pragmatism analysis to quantum mechanics seems prima facie problematic. The first has to do with explanation. As noted above, it would beg the question against the pragmatist to demand explanations in which quantum states describe physical systems. But if quantum claims do not have the function of describing the physical world, it does not seem out of place to expect such claims to be consistent with our ordinary non-quantum descriptions of physical systems, and hence to expect explanations in non-quantum terms. In an interference experiment, we can describe the preparation of the system in terms of the locations of objects, and the results in terms of the locations of objects, so why not the processes during the intervening time?

 Can decoherence provide a satisfactory answer to this question? Certainly decoherence provides a mathematical demarcation between situations in which non-quantum descriptions are appropriate and those in which they are not. But how does decoherence perform this feat? Physicists are happy to provide descriptive explanations: in the Juffmann experiment, decoherence occurs at the silicon surface because an incoming C60 molecule collides with the silicon molecules in the surface, exchanging energy in complicated ways (2004, 712). According to Healey, however, since it is decoherence that provides the precondition for non-quantum claims to be assertable, no explanation of decoherence in terms of molecular collision is possible. Decoherence is central to the pragmatist framework, but according to that framework, descriptive explanations of decoherence are ruled out. Decoherence tells us *when* non-quantum descriptions are possible and when they are not, but it cannot tell us *why*.

So decoherence doesn’t explain why non-quantum descriptions are unavailable prior to decoherence. Can we appeal to the no-go theorems to provide this explanation? The no-go theorems show that the prescriptive content of the quantum state cannot be realized by a descriptive model of a certain sort, a model in which every observable has a determinate value. That is, the no-go theorems preclude one kind of model; but others are available, notably Bohm, spontaneous collapse, and Everett. In addition, Friederich (2015, 161) suggests that a model in which every observable has a sharp value is *not* ruled out by the no-go theorems, although he doesn’t explicitly construct such a model. Of course, this would take us back to the project of *solving* the measurement problem that the pragmatist project is designed to avoid. If the pragmatist approach is to succeed in *dissolving* the measurement problem, it should show us why trying to construct a descriptive account of quantum processes is not just problematic, but conceptually misguided. That is, it should give us a principled explanation of the inapplicability of non-quantum descriptions to systems between preparation and measurement. Analogy with other pragmatist projects, for example concerning the status of moral claims, provides little guidance as to why that should be the case.

 A second sense in which the distinctive features of quantum pragmatism might be problematic is that the content of descriptive claims can change radically over time. Consider the time period during which a C60 molecule approaches and adheres to the silicon surface. After it has adhered, the claim that the molecule has a particular location has straightforward descriptive content. But just prior to this point, the quantum state has not yet decohered, and the claim that the molecule has a particular location lacks content (according to Healey), or at least has significantly modified content. That is, the content of a claim is highly sensitive to the *physical* context in which that claim is made.

 This is again a radical departure from other applications of pragmatism. The pragmatist can certainly account for contextuality of content: the give and take of reasons is a social process, so the meaning of a claim can be sensitive to the social context. But it is hard to see why the content of a claim should depend on the *physical* context. Sometimes *we make* the physical context relevant, for example when we say “Gold is whatever is of the same kind as *this*,” pointing at a sample. But there is no indexicality of this kind when I ascribe a location to a molecule. Why should the *meaning* (as opposed to the truth) of my utterance “The molecule is in region R” depend on the physical state of the target system? According to the pragmatist approach, whether you should take my utterance as meaningful or (practically) meaningless depends on whether decoherence has occurred: it can be meaningless at one moment, and meaningful a fraction of a second later. This is very strange semantic behavior. Of course, strange consequences are typical of interpretations of quantum mechanics, and perhaps this is a consequence we can live with. But it does seem that the pragmatist approach *relocates* the problematic aspects of quantum mechanics rather than dissolving them.

 Again, Friederich avoids this consequence, but at a cost. Friederich is open to the possibility that claims about the molecule’s position always have content, based on his proposal of sharp values for all observables (2015, 79). However, again this speculation undermines the advantages of the pragmatist approach, in that it suggests that quantum mechanics is incomplete as it stands.

 So there are at least two ways in which the application of pragmatism to dissolve the foundational problems of quantum mechanics differs from other applications. When I say “Kicking your sister is bad,” I don’t preclude physiological descriptions of kicking, yet a quantum claim can preclude non-quantum descriptions of a system. And the content of a physiological claim about kicking doesn’t change radically over time depending on the physical state of the person concerned, but the content of a non-quantum claims about a molecule does change radically over time depending on the physical state of the system concerned. Perhaps this means that there is something problematic in the way Healey (in particular) employs pragmatism to help us understand the way quantum mechanics works. Or perhaps it just means that the application of pragmatism to quantum mechanics is a unique case, and further philosophical therapy can dissolve these remaining concerns too.

**6. Conclusion**

I have done nothing here to evaluate the general pragmatist approach to meaning. But if it is otherwise defensible, it certainly seems like a good place to look for a dissolution of the foundational problems of quantum mechanics. The notable successes of pragmatism lie in areas where a straightforward realism lands us in deep philosophical difficulties—about mathematical entities, for example, or moral properties. And that is not a bad initial diagnosis of the situation regarding quantum mechanics: it is an excellent instrumental recipe, but taking quantum claims as literally representational quickly leads to problems, the measurement problem among them.

 So the pragmatist approaches of Healey and Friederich are welcome. And their proposal for understanding quantum claims—as prescriptive of our degrees of belief in non-quantum claims—has a good deal of initial plausibility. But it is also important to note the ways in which the application of pragmatism to quantum mechanics differs from previous pragmatist projects. Generally in such projects, a domain of statements is singled out as having a function other than representation, but the representational work of other statements in the vicinity goes on unchanged. Things are less straightforward in quantum mechanics, where the identification of quantum claims as performing a prescriptive function apparently also sharply circumscribes the applicability of representational non-quantum claims to physical systems. Hence a certain representational kind of explanation is also circumscribed: it is only available after decoherence, so representational explanation prior to decoherence, or of decoherence itself, is ruled out. Furthermore, the content of non-quantum claims exhibits an unusual kind of dependence on the physical context, so that a claim about the location of a molecule can be meaningless at one moment and meaningful the next. Again, this has no analog in standard applications of pragmatism.

 For these reasons, I think that further work is needed to ascertain whether pragmatist therapy can succeed in dissolving the problems of quantum mechanics. In particular, it looks like the pragmatist approach favored by Healey (and Friederich, insofar as he doesn’t go beyond the pragmatist approach) requires fairly radical changes to our understanding of propositional content and of explanation, even when compared to other pragmatist projects. The surrounding issue is whether the pragmatist approach, all things considered, is less problematic than realist approaches to the foundations of quantum mechanics. If so, then this could provide a powerful independent motivation to adopt the pragmatist program. But at present, I think this remains unresolved.

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