



# Barad, Bohr, and quantum mechanics

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## Abstract

The last decade has seen an increasing number of references to quantum mechanics in the humanities and social sciences. This development has in particular been driven by Karen Barad's agential realism: a theoretical framework that, based on Niels Bohr's interpretation of quantum mechanics, aims to inform social theorizing. In dealing with notions such as agency, power, and embodiment as well as the relation between the material and the discursive level, the influence of agential realism in fields such as feminist science studies and posthumanism has been profound. However, no one has hitherto paused to assess agential realism's proclaimed quantum mechanical origin including its relation to the writings of Niels Bohr. This is the task taken up here. We find that many of the implications that agential realism allegedly derives from a Bohrian interpretation of quantum mechanics dissent from Bohr's own views and are in conflict with those of other interpretations of quantum mechanics. Agential realism is at best consistent with quantum mechanics and consequently, it does not capture what quantum mechanics in any strict sense implies for social science or any other domain of inquiry. Agential realism may be interesting and thought provoking from the perspective of social theorizing, but it is neither sanctioned by quantum mechanics nor by Bohr's authority. This conclusion not only holds for agential realism in particular, it also serves as a general warning against the other attempts to use quantum mechanics in social theorizing.

**Keywords** Agential realism · Karen Barad · Niels Bohr · Quantum mechanics · Relational holism · Ontology

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## 1 Introduction

In recent years, there has been an explosion in references to and uses of quantum mechanics outside its traditional habitat of physics, quantum chemistry and philosophy of physics.<sup>1</sup> Interestingly, this expansion is not limited to neighboring fields. Rather, quantum mechanics now features as part of the inspiration for and justification of theorizing in disciplines and domains of inquiry typically labelled as social sciences or humanities.<sup>2</sup>

A prominent example of this trend is the work of Karen Barad and her agential realism as developed in *Meeting the Universe Halfway: Quantum Physics and the Entanglement of Matter and Meaning* (2007). As the title suggests, Barad here develops, among other things, a rethinking of the duality between matter and meaning, thereby echoing other new materialist voices<sup>3</sup> while insisting, however, that this rethinking is dictated by quantum mechanics. “Quantum physics, for Barad, is resolutely *not* a metaphor but, rather, underpins agential realism’s articulation of how the material world is brought into being” (Hollin et al., 2017, p. 935). Thus, quantum mechanics is not exemplifying agential realism but justifying it, as we shall argue below. Nevertheless, very few of the more than 8000 citations<sup>4</sup> of *Meeting the Universe Halfway* are in physics or philosophy of physics, which is arguably the natural home for discussions about the philosophical implications of quantum mechanics.<sup>5</sup> Rather, the influence of Barad’s agential realism has primarily been in cultural studies and social theorizing broadly construed [see Hollin et al. (2017) for further details]. However, this has not been a reason to disregard the quantum origin of agential realism. As de Freitas writes in a review of Barad’s work: “She shows how quantum physics can inform our thinking about gender, racial, queer and other differences” (2016, p. 150). The explicit interdisciplinary borrowing<sup>6</sup> from quantum mechanics is also testified by the use of agential realism under titles such as *Quantum Anthropologies* (Kirby, 2011), *The Entangled God: Divine Relationality and Quantum Physics* (Wegter-McNelly, 2011), “Quantum Sustainable Organizing Theory” (Dyck & Greidanus, 2016), “Critical Naturalism: A Quantum Mechanical

<sup>1</sup> We are aware that quantum mechanics, and the practice involving it, have been *studied* extensively outside these mentioned disciplines by researchers in history, science studies and cultural studies (e.g. Aronowitz, 1988; Harding, 1986, 1991; Hayles, 1984; Keller, 1995; Pickering, 1984; Plotnitsky, 1994). We distinguish, however, these from *uses* of quantum mechanics where it features as part of the justification of or inspiration for the developed theorizing. In other words, when quantum mechanics is used—the instances we are interested in here –, quantum mechanics is not (only) the object of study, but part of the theoretical complex that informs that study.

<sup>2</sup> As one researcher remarks in a recent discussion of Barad’s influence in social science: “More recently, in many areas of social and philosophical research, the ‘quantum’ label has become extremely desirable” (Dunk, 2019, p. 1).

<sup>3</sup> For a survey of these see, for instance, Dolphijn and Van de Tuin (2012).

<sup>4</sup> As recorded by Google Scholar in February 2020.

<sup>5</sup> Neither Barad nor any of the other exponents of the use of quantum mechanics in social theorizing have published their findings in physics or philosophy of physics venues, though Barad (1984, 1988) has a couple of mainstream physics publications that, however, do not mention agential realism.

<sup>6</sup> Following the terminology of Klein (1990).

Ethics” (Dolphijn, 2016), “What ever happened to quantum geography?” (Smith, 2016), and *Quantum Art & Uncertainty* (Thomas, 2018).

Despite this widespread reception of agential realism and the explicit role of quantum mechanics in its conception, neither Barad nor anyone else have taken up the task to connect agential realism with the vast literature on the various interpretations of quantum mechanics.<sup>7</sup> Such a discussion is of particular importance, since Barad’s account of quantum mechanics is closely informed by Niels Bohr’s interpretation. Until now, it therefore remains underexplored to what extent Barad’s presentation of quantum mechanics—which often reads as though it is the only possible interpretation—relies on Bohr’s seminal view on quantum mechanics and, as we shall also discuss, Barad’s idiosyncratic reading of Bohr. With respect to the latter, Barad (2007, p. 122) does explicitly recognize that her realist reading of Bohr stands out, but remarks that she in this reading is in the good company of the renowned Bohr scholar Henry Folse.<sup>8</sup>

In contrast, we shall argue that Barad’s interpretation of Bohr and her account of the implication this has for understanding quantum mechanics depart in important respects from all other readings of Bohr’s interpretation. Additionally, we show that many of the more profound implications—including the rethinking of the matter/meaning dualism—are inconsistent with the mainstream interpretations of Bohr and other prominent interpretations of quantum mechanics. This includes Rovelli’s (1996) relational quantum mechanics, which Barad accentuates as similar to her own interpretation. These discussions also serve as an occasion to detail Bohr’s use of the term ‘phenomenon’; an otherwise little studied aspect. Phenomena (in Bohr’s sense) are promoted by Barad to be the basic ontological unit, whereas we try to document that Bohr intended phenomena to be derivative and entirely epistemic.

While these clarifications might come across as exegetical, they are called for by the widespread reception of Barad’s account of quantum mechanics—in the form of agential realism—in the social sciences and humanities. Researchers in these fields cannot be expected to have any familiarity with quantum mechanics. So, if their only exposure to quantum mechanics is through Barad—or any other of the translators of quantum mechanics mentioned below—they will invariably inherit the idiosyncratic interpretation of quantum mechanics that Barad expounds without, however, realizing its controversial nature (Jakslund, 2020).<sup>9</sup> When we here expose these idiosyncrasies, we do so in order for users of Barad’s work to become aware that the

<sup>7</sup> Barad (2007, p. 287) lists various other approaches to quantum mechanics including many worlds interpretation, Bohmian mechanics, spontaneous collapse theory, and decoherence, but none of them are expanded upon or related to Barad’s agential realism that is based on her Bohr-interpretation. Those that have discussed agential realism in a philosophy of physics context have had their focus elsewhere; examples being Harrell’s (2016, Sect. 2.3.3) account of agential realism as a feminist philosophy of physics and Richardson (2010, p. 349) who situates agential realism in the broader context of feminist philosophy of science.

<sup>8</sup> Furthermore, Barad insists that her account is “in considerable agreement with individual features of many of the standard secondary texts on Bohr’s philosophy of physics” (2007, 122).

<sup>9</sup> This risk is exemplified when Vicky Kirby relies on Barad as the sole resource on quantum mechanics in a book titled *Quantum Anthropologies* and where quantum mechanics is described as being “of crucial importance for my argument” (Kirby, 2011, p. 76).

interpretation of quantum mechanics is an expansive field of research with many deviating conceptions. Barad is not revealing the truth about quantum mechanics, but rather one among many possible interpretations and one, we argue, whose very coherence is still in need of further scrutiny. Moreover, our finding of important differences between Barad and Bohr shows that his authority does *not* sanction agential realism.

The discussion of Barad, Bohr, and quantum mechanics also serves to renounce the impression—found among many readers of Barad, if not in Barad’s own work—that Barad is the first since Bohr (and Heisenberg) to consider the philosophical implications of quantum mechanics. In an appreciation of Barad’s work, Vetlesen admires “[t]he way she goes about actualizing and further elaborating Bohr’s contribution—long neglected among the majority of philosophers—is original and thought provoking” (2019, p. 126). Similarly, Pinch finds “one of the great merits of Barad’s work—and this is a real contribution—to be how she teases out and recovers what Bohr actually meant and the radical nature of his take on the issues” (2011, p. 437). To contrast this narrative, we relate Barad’s work to the many other good works on Bohr and the philosophy of quantum mechanics more generally that has been published *continuously* over the last century. Finally, seen from the perspective of philosophy of physics, this paper forms the first assessment of Barad’s claim that agential realism, apart from its importance to social theorizing, is “making a specific scientific contribution to an active scientific research field (i.e., the foundations of quantum physics)” (2007, p. 36).

As already mentioned, the expansion of quantum mechanics into the social sciences and humanities has many routes beyond Barad’s work, and many of the warnings issued here regarding Barad’s work and its use in these fields of inquiry are equally relevant for many of the other recent speculative uses of quantum mechanics outside of physics. Most of these also depend on very idiosyncratic interpretations of quantum mechanics, often extended well beyond the regime where their application is empirically justified. Alexander Wendt, for instance, in his *Quantum Social Science* (2015) speculates that consciousness originates in quantum effects.<sup>10</sup> This hypothesis is not in itself new but based on more thorough—though still highly speculative—work by Hameroff and Penrose (1996a, b, 2014). However, like Barad, Wendt conjectures that these quantum effects (now in consciousness) have profound consequences for social theorizing. As summarized by Fuller (2018, p. 179): “Considering human psychology in properly quantum terms means that the difference between an agent and its environment does not amount to two physically separated bodies but rather two overlapping spheres of possible action.” In our view, this and similar speculations found in Wendt’s work and in those using it resemble the patterns of the theoretical complex surrounding Barad’s work. We therefore suspect that many of the warnings issued here with respect to Barad also apply to Wendt and other translators from quantum mechanics to social theorizing. And these warnings are important, since Wendt and others—like Barad—have seen widespread

<sup>10</sup> See also Nadeau and Kafatos (2001), Grandy (2010), and Haven and Khrennikov (2013) to name a few.

reception among researchers who rely on them as authorities on quantum mechanics; in the case of Wendt, this is exemplified by Bowman (2019) among many others. While we will here only engage with Barad's work, we call on others to conduct similar investigations into these other translators—Wendt in particular—and their interpretation of quantum mechanics as compared to the philosophy of physics mainstream.<sup>11</sup>

The paper proceeds as follows: Sect. 2 introduces Barad's agential realism with a focus on quantum mechanics and her use of Bohr's philosophy. In Sect. 3, we go on to argue that much of Barad's ontologically loaded interpretation of quantum mechanics in the form of "phenomena" finds no warrant in Bohr's writings. Section 4 continues with an exploration of Bohr's attitude towards those dualisms that Barad claims he rejects. The final Sect. 5 investigates, but ultimately refutes, Barad's (2007, p. 24) claim that agential realism captures the consequences of quantum mechanics for all domains of inquiry including social theorizing. First, we show by example of Bohmian mechanics that other interpretations of quantum mechanics feature a metaphysics that is profoundly different from that of agential realism. Second, we find that even Rovelli's (1996) relational quantum mechanics—that Barad offers as a similar interpretation—is different from agential realism in important respects: This includes details in their respective response to the measurement problem, where the deviations of agential realism might in our view compromise its coherence. We conclude, therefore, that neither Bohr nor quantum mechanics as a whole proves Barad's agential realism to be true. Barad's ideas are profound, interesting, and thought provoking, but like any other piece of social theorizing, agential realism must earn its merits, if any, by its utility and not by its quantum mechanical origin.

## 2 Agential realism

This is not the place to give a full account of Barad's agential realism with all its complexities. Our more modest ambition is to explicate those aspects of agential realism that relate directly to Bohr's writings and quantum mechanics emphasizing along the way how Bohr and quantum mechanics are invoked by Barad. This is not the place either to summarize the content and history of quantum mechanics; though we will try to make the following as self-contained as possible.

In classical mechanics, particles carry both a definite position and momentum. The knowledge of these properties, together with that of the forces acting on the particle, is used to predict a particle's future path. In quantum mechanics, this knowledge breaks down since certain pairs of properties—position and momentum among

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<sup>11</sup> Part of such a critical assessment of Wendt's work has already been conducted by DeCanio (2017) and Waldner (2017), the latter concluding: "The moral of this story is that, in all likelihood, we do not need to become quantum social scientists" (Waldner, 2017, p. 200). It is a similar conclusion that we advocate with respect to Barad's agential realism.

them—are in a sense mutually incompatible.<sup>12</sup> One cannot ascribe at the same time a definite position and a definite momentum to a quantum mechanical object. This feature is captured in Heisenberg’s indeterminacy<sup>13</sup> relation according to which there is a reciprocal relation between the indeterminacy of two such incompatible properties. In other words, if the position of a particle is exactly determinate, then its momentum must be completely indeterminate to satisfy the indeterminacy relation, and in most cases, both the value of position and momentum will be indeterminate.

Evidently, we never see such indeterminacy in experiments.<sup>14</sup> An electron is never measured to be in more places at once or as traveling with multiple speeds at the same time. When we measure the value of a property, for instance position, the quantum system is forced to settle on a specific value for position among the values in the range of the preceding indeterminacy.<sup>15</sup> One might then propose that the indeterminacy relation can be violated if we quickly measure the momentum after the position measurement. This will indeed give a determinate value for momentum; however, if we measure the position again afterwards, the two position measurements will not agree. In fact, there will be *no* correlation between the measured positions of a particle, if we measure momentum in-between each position measurement. The momentum measurement reinstates the indeterminacy of position.<sup>16</sup> In a sense, the mutually incompatible properties—like position and momentum—are associated with mutually incompatible experiments where, if you choose a set-up that measures one property, you at the same time prohibit a set-up that can measure another property.

While most interpretations of quantum mechanics have little to say about this mutual incompatibility of experiments, it becomes central to Bohr’s notion of complementarity. “The apparently incompatible sorts of information about the behavior of the object under examination which we get by different experimental arrangements can clearly not be brought into connection with each other in the usual way, but may as equally essential for an exhaustive account of all experience, be regarded

<sup>12</sup> More precisely, the operators related to the two incompatible properties do not commute.

<sup>13</sup> We use ‘indeterminacy principle’ instead of the more common ‘uncertainty principle’ to signify that the reciprocal relation and therefore mutual incompatibility between pairs of properties are for Barad not the artefacts of our lacking knowledge of the system under investigation. Rather, these are genuinely inscrutable indeterminacies. See Faye (2019) for further details on this distinction, which we shall also return to in Sect. 5 in our discussion of Bohmian mechanics.

<sup>14</sup> We do, of course, often have some measurement inaccuracy such that the position or momentum—whatever we measure—is only known with a certain precision. This uncertainty, however, is different from the indeterminacy in quantum mechanics.

<sup>15</sup> What exactly happens when the wave function ‘collapses’ onto a particular value of a property (an eigenvalue in technical terms) is the center of the debate over the measurement problem in quantum mechanics. The account given here attempts to describe what happens *according to the quantum formalism*, and different interpretations of quantum mechanics will provide different stories for the associated ontology, as we shall see in Sect. 5.

<sup>16</sup> This is perhaps better illustrated with spin. If we consider a spin- $\frac{1}{2}$  particle and do interchanging measurements of its spin in two orthogonal directions, we will find that there is no correlation between the spin-measurement in the same direction. The probability of getting spin up would be 0.5, if the preceding spin measurement were made in an orthogonal direction, even if the previous measurement in the first direction had yielded spin up.

as ‘complementary’ to each other” (Bohr, [1937] 1998, pp. 84–85). When the physicists choose between mutually incompatible experimental arrangements, they select a particular measuring instrument, which they already know allows them to describe the outcome in terms of some property-concept, like position or momentum.

Thus, according to Bohr, in quantum mechanics there is an integration between the use of concepts such as ‘position’, the property to which the concepts refer, and the context of measurement. And these complexes come in complementary pairs, again position and momentum being an example, but Bohr also mentions complementarity between energy and duration and wave and particle descriptions, among others. The ascription of properties entering in complementary pairs is only meaningful relative to an experimental set-up that measures the property in question, Bohr argues, and qua complementary the pairs are not applicable to a system at the same time.

As such, the defining conditions for the ascription of a property in a complementary pair to a quantum object are provided by the experimental set-up, according to Bohr, and these conditions are mutually exclusive: “the ascription of [complementary] properties to the object as it exists independently of a specific experimental interaction is ill-defined” (Faye, 2019). According to this view—often known as Bohr’s *contextualism*—the mutual exclusion due to complementarity entails that a measurement context where a quantum object has a determinate position, renders the attribution of the concept ‘momentum’ unintelligible, and similarly for other complementary pairs.

Barad summarizes Bohr’s view in the following way (using the example of position):

“position” only has meaning when a rigid apparatus with fixed parts is used [...]. And furthermore, any measurement of “position” using this apparatus cannot be attributed to some abstract independently existing “object” but rather is a property of the *phenomenon*—the inseparability of “observed object” and “agencies of observation”<sup>17</sup> (2003, 814, emphasis in original).

On Barad’s reading of Bohr, it is not the quantum object that has a property in an experimental context, but rather it is the relationality of quantum object and experimental set-up, the “phenomenon,” that has the property. This relationality—as captured by the phenomenon—is the cornerstone in Barad’s ontological framework and the composition metaphor implicit in the quotation above should only be assigned instructional significance<sup>18</sup>:

phenomena do not merely mark the epistemological inseparability of “observer” and “observed”; rather, *phenomena are the ontological inseparability of agentially intra-acting “components.”* That is, phenomena are onto-

<sup>17</sup> Barad borrows the notions ‘phenomenon’ and ‘agencies of observation’ directly from Bohr though she arguably distorts, as we shall see, their meaning for her own purposes.

<sup>18</sup> This leads Barad to argue that the separation between object and apparatus is not fixed; a view that Heisenberg advocates in opposition to Bohr (Bächtold, 2017; Schlosshauer & Camilleri, 2017).

logically primitive relations—relations without preexisting relations<sup>19</sup> (Barad 2003, 815, emphasis in original).

The phenomena do not emerge from the *inter*-action between object and measurement apparatus (agency of observation). Phenomena should rather be considered as ontologically primitive, and it is specific *intra*-actions within phenomena that give rise to the separation into observed object and apparatus.<sup>20</sup> In more technical terms, Barad defends this by observing that the object and the measuring apparatus become entangled upon measurement, whereby they, according to the quantum formalism, cannot be described as two separate interacting systems. Instead, they form a non-separable whole, and Barad takes this to explain why phenomena (in her use of the term) must be the ontological primitive: “phenomena are the ontological entanglement of objects and agencies of observation. Hence it is the ontological inseparability or entanglement of the object and the agencies of observation that is the basis for complementarity” (Barad, 2007, p. 309). The latter follows, according to Barad, since the entanglement between an object and an apparatus measuring one of a complementary pair of properties precludes the entanglement with an apparatus measuring the complementary property. From this, Barad concludes that “Bohr constructs his post-Newtonian framework on the basis of ‘quantum wholeness’ or inseparability, that is, the lack of an inherent distinction between the object and the agencies of observation” (Barad, 2007, p. 196).

According to Barad, it follows from these observations that quantum mechanics does away with the “metaphysics of individualism” (Barad, 2007, p. 195), which she elsewhere qualifies as the “conventional (Newtonian) view of metaphysics, whereby there are individual objects with individually determinate properties, and measurements reveal the preexisting values of particular physical quantities” (Barad, 2007, p. 262). In contrast, Barad’s Bohr-inspired interpretation of quantum mechanics hosts no individual objects with properties and renounces explicitly even cautious forms of entity realism typically explicated along the following lines: “Experimenting on an entity does not commit you to believing that it exists. Only manipulating an entity, in order to experiment on something else, need do that” (Hacking, 1983, p. 263; quoted in Barad, 2007, p. 357). Only phenomena—the inseparable whole from which objects and measurement apparatus derive—are the fundamentally real, and properties must therefore instead be ascribed to these phenomena. Even the configuration of components within phenomena including their mutual boundaries is variable, since they, according to Barad, are enacted by the specifics of an experimental practice. More generally, it is these “boundary-making practices that produce ‘objects’ and ‘subjects’ and other differences out of, and in terms of, a changing

<sup>19</sup> In this regard, agential realism likens ontic structural realism (e.g. French & Ladyman, 2003), but this similarity will not be pursued further here.

<sup>20</sup> As Vetlesen (2019, chap. 3) observes, what these *intra*-actions involve and how they enact the different configurations of object and agency of observation are never sufficiently explicated; especially beyond a laboratory setting of quantum mechanics.



relationality” (Barad, 2007, p. 93).<sup>21</sup> Neither the observed object, nor the measurement apparatus and the experimenter exist prior to the measurement, and none of them can therefore have determinate pre-existing properties. Furthermore, with subject and object being variable and derivative categories, Barad questions traditional dualism of subject-object and knower-known<sup>22</sup>: These dualisms are not inherent but come into being through intra-actions within phenomena.

The complementarity of properties—including the complementarity of the associated concepts and experimental setups—only amplifies this effect. According to Bohr, the concept ‘position’ is only meaningful in an experimental context that measures position and in this context, ‘momentum’ is ill defined. In Barad’s view, this relationship introduces a materiality or embodiment to words and even to meaning itself. “It is through specific agential intra-actions that the boundaries and properties of the causally related components of phenomena become ontologically determinate and that particular concepts become meaningful (that is, semantically, determinate)” (Barad, 2007, p. 339). Words, world, and meaning are co-produced by intra-actions within phenomena, which refute “the independently determinate existence of words and things” (Barad, 2007, p. 107).<sup>23</sup> The dualisms of word-world and material-discursive cannot be sustained, since the complementarity of properties in quantum mechanics entails that configurations of phenomena only admit certain embodied concepts and meanings while excluding other complementary ones: “the physical and conceptual apparatuses form a nondualistic whole” (Barad, 2007, p. 196).<sup>24</sup>

In summary, Barad argues that phenomena—the whole from which specific material configurations derive—are the ontologically primitive entities. The boundaries between object and agency of observation are not inherent, and the same goes for those of subject-object and knower-known. Even the word-world dualism is rejected because of the material conditions for the attribution of complementary concepts. “For Bohr, things do not have inherently determinate boundaries or properties, and words do not have inherently determinate meanings. Bohr also calls into question the related Cartesian belief in the inherent distinction between subject and object, and knower and known” (Barad, 2007, p. 138).

<sup>21</sup> As such, both knowledge and agency are also to be ascribed to the phenomena as a whole; something that Barad employs as part of a posthumanist and new materialist program. However, we shall not discuss these positions further here.

<sup>22</sup> Barad summarizes the knower/known dualism as the view “that measurements reveal the preexisting values of the properties of independently existing objects as separate from the measuring agencies” (Barad, 2007, p. 107).

<sup>23</sup> Barad elaborates: “Meaning is not a property of individual words or groups of words but an ongoing performance of the world in its differential dance of intelligibility and unintelligibility” (Barad, 2007, p. 149).

<sup>24</sup> More precisely, an experimental set-up is “giving determinate meaning to those concepts embodied in the apparatus (to the exclusion of other complementary concepts)” (Barad, 2007, p. 330). By this exclusion, the intra-actions exacting configurations are in this sense “agential” and a pervasive agency therefore prevails in Barad’s agential realism. “In my agential realist elaboration of Bohr’s account, *apparatuses are the material conditions of possibility and impossibility of mattering*; they enact what matters and what is excluded from mattering” (Barad, 2007, p. 148, emphasis in original).

### 3 Bohr on 'Phenomena' and realism

Barad's summary, however, is not entirely faithful to Bohr's view. Indeed, Barad already goes well beyond what Bohr seems to have had in mind when she promotes the phenomenon to an ontological unit and one that comprises of (or in her terms enacts) both object, experiment and experimenter. Barad does recognize that her presentation of Bohr's view is more ontological, than the epistemological voice found in Bohr's own account. However, Barad merely describes this as "[d]rawing out the ontological dimensions of Bohr's framework" (2007, p. 174).

Since many readers of Bohr's writings have complained that his essays are obscure and difficult to read, we shall establish some terminology. Bohr distinguishes between object, measuring instrument, measurement, and phenomenon. The atomic object is the physical system about which physicists want to get information, and in order to receive some information about the object the physicists apply a measuring instrument to interact with the object. The application of the measuring instrument to the object is the same as carrying out an experiment. A phenomenon is the outcome of a measurement, or rather a combination of two measurements. First, we need a measurement that determines the initial value of either a position or a momentum to be able to predict the behavior of the object; second, we need a later measurement that determine a new value of either a position or a momentum to see, whether or not the object behaves according to the quantum mechanical predictions. Thus, a phenomenon in Bohr's use of the word is how the quantum object appears during the interaction with a particular measuring instrument. In quantum mechanics, the interaction has "an essential influence on the phenomenon itself;" i.e., on what is actually measured.

Bohr does, with his notion of phenomena, promote an integrated view of the experimental contexts when he finds that it is "in accordance with the structure and interpretation of the quantum mechanical symbolism, as well as with elementary epistemological principles, to reserve the word 'phenomenon' for the comprehension of the effects observed under given experimental conditions" (Bohr, [1938] 1998, p. 104). However, Bohr emphasizes that the word "phenomenon" refers to an *effect* (or the outcome) that appears whenever the interaction between an object and a measuring instrument takes place. This effect, i.e. the phenomenon, is the manifestation of a property that only exists in virtue of the interaction. It belongs neither to the object itself nor to the measuring instrument.

But Barad misreads Bohr as if he was saying that, say, the position is a property of the phenomenon, whereas Bohr holds that the phenomenon is identical to the manifestation of a quantitative property that atomic objects can be attributed only because of its interaction with the measuring instrument. Thus, a phenomenon does not have an independent ontological status but depends on an interaction of the atomic object and the measuring instrument. Both of which, by the operational presumption of doing science, are presumed to be independently real. This conception is well supported by other occurrences of 'phenomenon' in Bohr's writings, for instance when he discusses "*the impossibility of any sharp separation between the behaviour of atomic objects and the interaction with the*

*measuring instruments which serve to define the conditions under which the phenomena appear*” (Bohr, 1949, p. 210, emphasis in original). Here Bohr distinguishes between “the phenomena” and the experimental conditions under which these phenomena appear.

Moreover, he tells us that what defines these conditions is the measuring device in question. Epistemically, we have to distinguish between the phenomenon and the measuring instrument, although the choice of measuring instrument informs us about which kind of phenomenon we can expect to observe. A similar remark is true of the following statement of Bohr: “I advocated the application of the word *phenomenon* exclusively to refer to the observation obtained under specific circumstances, including an account of the whole experimental arrangement” (Bohr, 1949, pp. 237–238). Again, Bohr distinguishes between the phenomenon, which is the actual observation we produce by using a particular measuring instrument, and the specific circumstances under which we obtain this observation. The specific circumstances include the kind of measuring instrument by which the observation is carried out.

In our view, it is beyond doubt that Bohr regarded phenomena to be derivative from a pre-existing experimental set-up. In addition, we propose that phenomena are most appropriately regarded as an *epistemological* integration of the object of study and measuring apparatus; however, in such a way that they retain their ontological separateness. Moreover, although the uncontrollable interaction between the atomic object and the measuring instruments seems to involve the choice of an experimenter, Bohr warns us against thinking that the experimenter takes part in the result. As he says, “it is certainly not possible for the observer to influence the events which may appear under the conditions he has arranged” (Bohr, 1949, p. 223). This is at least an important qualification to Barad’s claim that “[a]ccording to Bohr, the central lesson of quantum mechanics is that we are part of the nature that we seek to understand” (Barad, 2007, p. 247). Bohr’s point merely seems to be that, just like in classical physics, the experimenter selects the kind of experiment she wants to run, but thereafter she has nothing to do with how the atomic object appears as a phenomenon having a precise value. Barad’s strong notion of intra-actions enacting cuts within the ontologically primitive phenomena finds no counterpart in Bohr’s interpretation of quantum mechanics.

Now, according to Bohr, no atomic object can be attributed classical kinematic or dynamic properties independently of the experimental set-up. Consequently, he denies that quantum objects have such properties intrinsically. He states this very clearly by saying: it is important to understand “that no result of an experiment concerning a phenomenon which, in principle, lies outside of classical physics can be interpreted as giving information about independent properties of the objects, but is inherently connected with a definite situation in the description of which the measuring instruments interacting with the objects also enter essentially” (Bohr, [1939] 1958, p. 26). However, it should again be emphasized that Bohr—in contrast to Barad—does not think that these relational properties exist as ontological primitive relations without pre-existing relata. For Bohr both atomic objects and instruments are real, and as such they figure as relata in a sentence like “... is recorded to have position  $p$  in relation to ...”. It is from this

perspective that we warn against Barad's ontologically realist interpretation of Bohr.

Barad is correct that there are realist interpretations of Bohr. However, rather than promoting a relational ontology like agential realism, these realist interpretations of Bohr take passages like the above to signify that Bohr was an entity realist. The first to promote this understanding of Bohr as an entity realist was Henry Folse (1986) of which Barad writes: "Henry Folse and I have been the strongest proponents of the minority view that sees Bohr as a realist, though we disagree about the nature of Bohr's realism" (Barad, 2007, p. 122). From this qualification, one might get the impression that the disagreements between Barad and Folse are merely cosmetic compared to their shared realist interpretation. However, the entity realism that Folse finds in Bohr's writings goes directly against Barad's interpretations of quantum mechanics, which explicitly denies entity realism.

An entity realist holds that experiments with the microscopic object tell us what is real and what is not [see Cartwright (1983) and Hacking (1983) for two authoritative accounts]. We find out about atoms by interacting with atomic systems, not by picturing them. So, according to Folse's interpretation of Bohr, Bohr held the view that whenever the physicists perform a measurement, the result is due to the fact that an object is actually being observed. The entity being observed is the atomic object that exists independently of the observation. Bohr was in other words a realist about atoms and atomic objects according to Folse. These entities have independent existence, but as such they are part of the fundamental ontology and *not*, as Barad insists, derivative from phenomena. Folse's realist interpretation of Bohr defeats rather than supports the ontological relational holism of agential realism. From this perspective, it might render agential realism more compatible with Bohr than realist interpretations of Bohr—as Barad's also remarks—are a minority view. However, in our assessment, most readers of Bohr will agree with the characterization of him as an entity realist. Although Faye (1991) calls Bohr an objective antirealist, he agrees that Bohr never denied the existence of atomic objects. Bohr's entity realism is why Faye considered him to be an *objective* antirealist but considered him to be an *anti-realist* with respect to theories. The disagreement between Folse and Faye was about whether or not Bohr believed that there exists something behind the phenomenon *that physicists could grasp neither experimentally nor theoretically*. Folse (1985) said yes, Faye (1991) no. Whether Folse is right or wrong, his realistic understanding of Bohr is very different from Barad's. Folse (1994) believes that an ontological commitment corresponding to Bohr's complementarity view would bring Bohr to embrace a distinction between atomic objects as real entities as they are in themselves, but unknowable to us, and as they appear to us in their interaction with the measuring instrument.

Zinkernagel (2016) and Halvorson (2019) have argued that Bohr held a more realist attitude towards the quantum formalism. Zinkernagel, however, concedes that Bohr mostly talks about epistemological and instrumental aspects of quantum mechanics as Bohr refers to descriptions of quantum system and to the theory as a tool for prediction. In spite of this concession, he also believes that Bohr sometimes attributed the wave function a representational status even though Bohr in

general characterized it as symbolic.<sup>25</sup> David Favrholt (1994) holds that Bohr is a realist who rejects the classical image of scientific knowledge as a God's eye view of nature. The discovery of the quantum of action shows that such an image is not possible, and it shows that a physical description cannot be about how nature is, but what we can say about it in an unambiguous and objective way. Such an unambiguous description is possible to the extent we are able to make a sharp distinction between the object and the measuring instrument by using the classical physical concepts and ordinary language. According to Favrholt, one commits to the existence of a mind-independent world by complying with the rules for the use of everyday language. So, when Bohr talks about using the ordinary language supplemented with technical terminology, he dedicates himself to realism. In combining realism with language-dependence, which integrates language and objectivity, Favrholt's is possibly the reading of Bohr that comes closest to Barad's.<sup>26</sup> Exploring the affinities between Barad and Favrholt would be an interesting exegetical exercise, but for another occasion.

Bohr did argue that the quantum object under investigation uncontrollably interacts with the measuring instrument, or as we usually say today, they are entangled. During a measurement the state of the target object and that of the measuring instrument are inseparable. However, he also argued that as long as we use classical concepts to secure an unambiguous description of the measurement outcome, we are *epistemically* justified in making a separation in our description of what we measure from our description of the instrument with which we do the measuring (Howard, 1994); a view that even Favrholt shares.<sup>27</sup> This is due to the fact that "the proper measuring instrument [...] serves to define the reference frame" (Bohr, 1949, p. 228) for our description of the quantum object and that we can disregard quantum effects in the account of the function of the instrument. In other words, we treat the measurement outcome as if it yields information about an object that exists separated from the instrument. At first sight, this is an epistemic and a practical distinction. However, it is not obvious what ontologically corresponds to this distinction since both the object and the instrument exist in an entangled state during the

<sup>25</sup> It remains a question of debate what Bohr's attitude towards the wave function exactly is and what Bohr takes to be the justification and philosophical implications of the insistence that complementary concepts are only meaningful in the relevant experimental context. Barad offers a distinctly ontological reading of Bohr, which marks it as rather unconventional in a field that primarily comprises of various non-ontological readings, the most common being: epistemic (e.g. Murdoch, 1987), pragmatist (e.g. Folse 2017; Stapp 1972), functionalist (e.g. Camilleri & Schlosshauer, 2015), Kantian (e.g. Honner, 1987), instrumentalist (e.g. Popper, 1962, chap. 3), or naturalist (e.g. Faye, 2017) readings of Bohr. Generally, any ontological reading has been strongly opposed by Bohr's former assistant Aage Petersen (1963).

<sup>26</sup> Barad (2007, footnote 94) mentions Favrholt (1994) in a list of other realist readings of Bohr, but does not elaborate further on the resemblances.

<sup>27</sup> Zinkernagel (2015, 2016) disputes that Bohr saw this need to epistemically separate the otherwise entangled object and measuring apparatus. Instead, Zinkernagel argues that Bohr considered the measuring apparatus as a whole to be classical and therefore not subject to entanglement. This, of course, is no better for Barad's proposal that Bohr considered object and measuring apparatus to be in an ontological quantum entangled state. Even though Bohr's view on entanglement is disputed, Barad stands alone with her ontological interpretation also on this point.

measurement. Probably Bohr did not really care. As he states, the purpose of quantum mechanics “is not to disclose the real essence of phenomena but only to track down, so far as it is possible, relations between the manifold aspects of experience” (Bohr, [1955] 1958, p. 71). The consequence is that “[t]he entire formalism is to be considered as a tool for deriving predictions of definite and statistical character...” (Bohr, [1948] 1998, p. 144).

Instead, Bohr claimed repeatedly that the wave function has only a symbolic character. In alignment with the symbolic character of the wave function, there is nearly consensus that Bohr never in his writings spoke about the collapse of the wave function, which would have made sense only if he considered the wave function to represent an objective physical state. A search of his writings also reveals that Bohr does not use the term “quantum states” (except when he talks about stationary states), which one would have expected he would have done if he had considered the wave function as representing an ontological state that undergoes an abrupt change into a classical state during the measurement. For Bohr there was no measurement problem, as many realists and representationalists believe.

Bohr’s view is still a type of relational holism, but an epistemic rather than ontological variant; indeed this epistemic relational holism is largely identical to that defended by Teller (1989), Faye (1991) and more recently by Dorato (2017). Quantum systems have classical properties only with respect to their interaction with the measuring instrument since the impossibility of their dynamical separation does not allow *describing* the phenomenon in isolation from the apparatus.

As we can see, several authors read Bohr realistically, but apart from holding that Bohr was an entity realist there seems to be little agreement whether and how his realism extends beyond that. However, it is also clear that Barad cannot find any support for her interpretation in *any* of these readings, which—perhaps apart from Favrholt’s—are all very different from her construal, and the same is true for other more anti-realist readings of Bohr.

## 4 Bohr and dualisms

With Bohr’s entity realism and the epistemic and derivative nature of phenomena, there seems to be little merit to Barad’s claim that Bohr questioned the epistemic dualisms of subject/object, knower/known, and word/world as we shall argue below.

As stated above, Bohr finds that we must treat measurement outcomes as though they yielded information about the object of study as separated from the measurement device. This, he argues, follows from the need to use classical concepts that ascribe properties to entities. However, due to complementarity it is necessary to accompany the use of these classical concepts with a specification of the experimental context, since it does make a difference for what we can measure. If anything, this condition for objective reporting on experiments that Bohr identifies presumes those very dualisms that Barad claims Bohr questions. To report on an experiment, we must, according to Bohr, speak *as though* there is a sharp separation between the object of study and the subject studying it; the latter including both measuring device and experimenter. And even these latter two are kept apart when Bohr argues

that the experimenter only affects the measurement on choosing which experimental set-up to use.

By a similar argument, the dualism of knower and known is intact and possibly even a precondition for Bohr's interpretation of quantum mechanics. The reporting of experiments is a sharing of knowledge. It is this sharing of knowledge that for Bohr is crucial. Indeed, it is the defining feature of an experiment:

The argument is simply that by the word 'experiment' we refer to a situation where we can tell others what we have done and what we have learned and that, therefore, the account of the experimental arrangement and of the results of observations must be expressed in unambiguous language with suitable application of the terminology of classical physics (Bohr, 1949, p. 209).

Again, this quote illustrates the role of subjects as separated from the objects studied in an experiment. But, more importantly, it emphasizes that the role of the experiment is to "tell others what we have done and what we have learned", i.e. to share knowledge among knowers. With the purpose of quantum mechanics being to find relations between aspects of experiences and experiments being the means of revealing these relations, knowers become the starting point for any venture into quantum mechanics. And the aim is to achieve sharable knowledge about quantum objects which thereby become the known. It seems, therefore, that the knower/known dualism is where Bohr's interpretation of quantum mechanics begins and ends.

As Bohr also emphasizes in the quotation, he finds that the terminology of classical physics is central for the "unambiguous" reporting on experiments. However, complementarity entails that the properties known from classical physics are not always applicable and that some of these are mutually exclusive. This does entail an integration of the material and discursive that goes beyond the generic relation between language and the world.<sup>28</sup> The classical terminology is inevitable, while quantum mechanics proves that the use of this terminology is restricted to experimental contexts that by complementarity excludes the meaningful ascription of other parts of the classical terminology. As Barad also finds, this contextualism in Bohr's interpretation introduces a form of extended material conditions for the ascription of these properties, where properties not only apply under specific circumstances,<sup>29</sup> but also where the meaningful ascription of one property renders another completely unintelligible. However, Barad seems to take it too far when she proposes that Bohr thereby denounces the word/world dualism and "the independently determinate existence of words and things" (Barad, 2007, p. 107), if she means by this anything stronger than this contextualism. Indeed, like the subject and the knower, the classical terminology seems to be fixed *prior* to the experiment. One might say that for Bohr, it is exactly the indispensability of ordinary language with its central role for classical terminology that induces the need for contextualism. Words,

<sup>28</sup> Representationalism is, of course, debated. However, many will agree that there is some elementary interdependence between language and the world; at least as it appears in our experience.

<sup>29</sup> That properties apply under specific circumstances is of course not peculiar to quantum mechanics.

world, and meaning are *not* co-produced. Rather, the classical terminology, adapted to our ordinary experiences, is given. Its pre-existing meaning restricts what counts as experiments by limiting those observations that can be expressed in unambiguous language, to use Bohr's terminology from the quotation above.

In contrast to what Barad (2007, p. 138) claims, Bohr does not call into question the dualisms of subject/object, knower/known, or word/world. If anything, these dualisms are at the foundation of Bohr's interpretation of quantum mechanics.

## 5 Agential realism and quantum mechanics

The more radical parts of agential realism—the ontological prioritizing of phenomena and the questioning of prominent epistemic dualism—are at tension with Bohr's writings. However, Barad's primary aim is after all not to interpret Bohr but to show what implications quantum mechanics must have in social theorizing. As she emphasizes, "I am not interested in drawing analogies between particles and people, the micro and the macro, the scientific and the social, nature and culture; rather, I am interested in understanding the epistemological and ontological issues that quantum physics forces us to confront" (Barad, 2007, p. 24). Agential realism is Barad's answer to this question. This section, however, argues that the adoption of agential realism is by no means forced upon us by quantum mechanics. It is well beyond the scope of this paper to discuss every detail of quantum mechanics up against Barad's interpretation. Rather, we shall provide a two-fold indirect argument to the effect that at best agential realism is consistent with quantum mechanics according to our current best understanding of the quantum world.

First, we argue by the example of Bohmian mechanics that there are interpretations of quantum mechanics that share very few features in common with agential realism. This suggests, as one might have expected, that agential realism is not entailed by quantum mechanics in any strict sense of entailment. Second, we compare agential realism to Rovelli's relational quantum mechanics which Barad (2007, p. 333) describes as similar to agential realism. The point of the comparison is to signify that agential realism has subtle differences even from relational quantum mechanics and that these differences importantly manifest themselves in the measurement problem where agential realism cannot help itself to the same solution as relational quantum mechanics. Indeed, the ontological inseparability of object and agency of observation indicates a tension in the solution to the measurement problem within agential realism. Thus, not only are there many other and very different interpretations of quantum mechanics, but it also remains to be clarified whether agential realism is even consistent with quantum mechanics, or so we argue.

The differences between agential realism and Bohmian mechanics are also noticed but not further developed by Pinch (2011). As Pinch observes, Bohm dissented from Bohr's view in two important respects: He rejected the inevitable role of the classical terminology advocating the development of a new quantum language. We only mention it to emphasize that Bohr's contextualism with its central role for the classical terminology is not generally accepted. Furthermore, it is in any case a philosophical question whose relevance is amplified by quantum mechanics, but



which quantum mechanics does nothing to answer. What we shall discuss in a bit more detail is Bohm's view—inherited from Einstein, de Broglie, and others—that what we described earlier as indeterminacy, for instance in Heisenberg's relations, should (in a particular sense that we return to below) be interpreted as mere uncertainty. These so-called hidden variable theories argue that quantum objects do have determinate trajectories through space, and that the wave function therefore gives an incomplete description of the system. Indeed, Bohm (1952) finds that the results of paradigmatic quantum experiments can be accounted for by the introduction of an additional dynamical equation—a guiding law—that relates the wave function to the change of the position of the particle, i.e. to the velocity. As is well known, the violation of Bell's (1964) inequalities entails that any such hidden variables theory must be non-local, meaning that it must feature action-at-a-distance.<sup>30</sup> Such non-locality appears in Bohmian mechanics when the velocity of a particle in entangled many-particle states is affected or guided instantaneously by the other particles irrespective of their mutual distance.

The interested reader can consult Goldstein (2017) and references therein for more on the technical details of Bohmian mechanics. We shall for present purposes simply observe that Bohmian mechanics reproduces all the predictions of quantum mechanics, while promoting a metaphysics that is significantly different from that of agential realism.<sup>31</sup> Recall that according to agential realism, there are no individual objects with determinate properties that are simply revealed by measurement and relatedly, complementarity signifies the metaphysical indeterminacy of the property not being measured. Phenomena are the fundamentally real from which the separation into object of study, apparatus and observer are derived with different *intra*-actions enacting different such boundaries. In comparison, the ontology of Bohmian mechanics<sup>32</sup> comprises of individual particles with determinate position and (instantaneous) velocity,<sup>33</sup> which provides for pre-determined trajectories through space and time.<sup>34</sup> Bohmian particles are individual “local beables” in the terminology of Bell (2001). Any event is accounted for in terms of these trajectories of the particles that constitute all elements involved in the event (Dürr et al., 2004). In a measurement, for instance, both the object of study and the measurement apparatus must be included in the Bohmian description to yield the correct results. As such, the entire universe should ideally be included in the Bohmian description.

<sup>30</sup> See also Barad (2007, chap. 7) for a detailed account of Bell's inequalities and their consequences for *local* hidden variable theories.

<sup>31</sup> We are not saying that Barad is unaware of Bohmian mechanics even though it is only mentioned once in the main text as part of a list of other interpretations of quantum mechanics (Barad, 2007, p. 287); none of which are discussed any further.

<sup>32</sup> We are not interested in an exegetical discussion about the details of Bohm's metaphysical commitments, but rather the contemporary conception of the ontology of Bohmian mechanics. For a historical account, see Seager (2018).

<sup>33</sup> Velocity is not an independent degree of freedom, since the Bohmian guiding law is a first order differential equation. Thereby, it directly relates position to velocity through the wave function.

<sup>34</sup> It remains an open question how to treat the wave function in Bohmian mechanics. To simplify the comparison with agential realism, the present account is implicitly assuming a dispositional interpretation of Bohmian mechanics (Belot, 2012; Esfeld et al., 2014).

This descriptive feature provides for two similarities to agential realism, but ultimately for many more differences. First, Bohmian mechanics erases the ontological division between the quantum objects and the experiments studying them, which also follows by their merging into phenomena in agential realism. Second, in order to reproduce quantum phenomenology, all properties apart from position and velocity are produced from the interaction between the quantum object and the apparatus (or more generally, the environment).<sup>35</sup> These properties—including energy, momentum, and spin—do not pre-exist the measurement; again, a thesis that is also central to agential realism. The import, however, is very different. In Bohmian mechanics, an experimental context does not project—or enact, as Barad would have it—these properties from indeterminate to determinate. Rather, these properties can simply be regarded as non-existing in Bohmian mechanics. They function as convenient book-keeping devices for the changing positions of particles which are ultimately real<sup>36</sup>: “the state of a physical system is completely and precisely determined, at any moment in time, by the actual particle positions and the wave function, fixing how the positions change in time” (Lazarovici et al., 2018, p. 7).

The Bohmian ontology is in other words very different from the ontological relational holism of agential realism where “[b]oundaries, properties, and meanings are differentially enacted through the intra-activity of mattering” (Barad, 2007, p. 392). In Bohmian mechanics, quantum object, apparatus, and observer are all part of the universe’s determinate configuration of individual interacting particles in space that evolves entirely deterministically by specified laws of motion. The non-locality of the Bohmian guiding law entails that there is an intrinsic interconnectedness in this ontology; however, it is an interconnectedness between individuals. Again, our point here is not to promote Bohmian mechanics on behalf of Barad’s agential realism. Instead, the case of Bohmian mechanics shows that agential realism is *not* exposing “the epistemological and ontological issues that quantum physics forces us to confront” (Barad, 2007, p. 24). At best, agential realism provides us with the epistemological and ontological implications of one particular interpretation of quantum mechanics, whereas the same sorts of implications are very different in other interpretations.

That the implications are different *in crucial respects* in other interpretations is even the case for those interpretations that Barad finds to “have important features in common with each other and with the view [agential realism] presented here” (Barad, 2007, p. 333). These (allegedly) associated interpretations are Mermin’s (1998) Ithaca interpretation and Rovelli’s (1996) relational quantum mechanics. The latter in particular is superficially similar to agential realism in its account

<sup>35</sup> Formally, this follows from a no-go theorem due to Kochen and Specker (1968), but more heuristically Bohmian mechanics must still reproduce the apparent indeterminacy in quantum mechanics discussed in Sect. 2. Bohmian particles are, in this sense, not classical particles even though Bohmian mechanics is sometimes (mistakenly) portrayed as classical mechanics with non-local interactions among particles.

<sup>36</sup> It may sound absurd to denounce the existence of these other “observables” in quantum mechanics; however, as argued by Lazarovici et al. (2018) among others, what we ultimately measure are positions and changes of position. None of the other observables are directly observable.

of measurement, properties, and observers. Relational quantum mechanics rejects “the notion of observer-independent values of physical quantities” (Rovelli, 1996, p. 1637). This immediately entails that one cannot ascribe determinate values of properties to quantum objects as they are in themselves. Rovelli, however, goes further and argues that such values are observer-dependent in the sense that they are never intrinsic to the quantum object: “Value actualization is a relational notion like velocity” (Rovelli, 2018, p. 6). The velocity of something is always relative to some observer<sup>37</sup> and the same is the case for the value of all properties in relational quantum mechanics. While Rovelli’s mode of presentation remains one where the value is ascribed to the observed object or system, it seems equivalent to adopt a more relational mode where velocity, for instance, is the relative movement of observer and observed. This comes very close to Barad’s ascription of properties to the relational whole of phenomena.

Furthermore, as is also the case in agential realism, there is no inherent boundary between object and observer in relational quantum mechanics: “Standard quantum mechanics requires us to distinguish system from observer, but it allows us freedom in drawing the line that distinguishes the two” (Rovelli, 1996, p. 1643). This split—or agential cut in Barad’s terminology—is required, according to Rovelli, since the observer cannot be part of the quantum mechanical description in terms of wave function, if the observer is to determine the value of some observable related to the object. This feature is central to Rovelli’s response to the measurement problem where  $O$  is an observer measuring and thereby observing a determinate value for some initially superposed observable of the system,  $S$ .

The unitary evolution does not break down for mysterious physical quantum jumps, due to unknown effects, but simply because  $O$  is not giving a full dynamical description of the interaction.  $O$  cannot have a full description of the interaction of  $S$  with himself ( $O$ ), because his information is correlation, and there is no meaning in being correlated with oneself (Rovelli, 1996, p. 1666).

Another observer,  $P$ , who describes the combined system of  $S$  and  $O$  prior to a measurement, will describe it as a superposed state where  $S$  and  $O$  are correlated (or entangled, in technical terms). There is no contradiction here, as Rovelli observes, since the determinate value ascribed by  $O$  to  $S$  is relative to  $O$ , whereas the superposed state is relative to  $P$ . In parallel, Barad emphasizes that “measuring agencies” cannot determine their entanglement with the measured system and remarks in reply to the measurement problem that:

we are either describing a mark on the ‘measuring agency’ [...], in which case what it measures is its correlation with the system with which it intra-acts, constituting a particular phenomenon; or we make a different placement of the

<sup>37</sup> It is important here to emphasize that relational quantum mechanics endorses a very liberal notion of ‘observer’ “where an observer can be any physical system” (Smerlak & Rovelli, 2007, p. 429). This might be another difference to agential realism where a measurement involves leaving a mark on the measuring agency.

agential cut, using a different experimental arrangement such that the complete ‘original’ phenomenon, this time including what was previously marked as the ‘measuring agency,’ is being measured by the ‘new’ ‘measuring agency,’ in which case it is possible to characterize the existing entanglement” (Barad, 2007, p. 348).

Analogous to relational quantum mechanics, the phenomenon constituted by the measuring agency and system has a determinate value for the measurement, whereas an outside observer has another description.

However, there are also important differences between these two solutions to the measurement problem. For Barad, there is no collapse or rather no destruction of the entanglement between observer and observed upon measurement. The appearance to the contrary arises from the fact that the measuring apparatus cannot measure itself; however, the entanglement is there all along: “we should not conclude from the fact that the entanglement is not made explicit by this measurement that the entanglement has become ontologically ‘disentangled’” (Barad, 2007, p. 348). As such, Barad seems to suggest that the description obtained by a measuring agency within a phenomenon is incomplete, since it does not include this “extension of entanglements that take place through measurement intra-actions” (Barad, 2007, p. 350). In contrast, Rovelli insists that the wave function with its superposition—and thus possible entanglement—is merely a bookkeeping device. Describing a quantum event as “the actualization of the value of a variable in an interaction”, Rovelli argues that “[t]he proper ontology for [relational quantum mechanics] is a sparse ontology of (relational) quantum events happening at interactions between physical systems” (2018, p. 7; see also Smerlak & Rovelli, 2007). The world consists of a sequence of interactions between systems where physical quantities take determinate values, which means, of course, that the systems precede the interactions.

While the values remain relational, this ontology of real systems and interactions is profoundly different from the relational holism entailed by the treatment of phenomena as the ontological primitive in agential realism. In this case, however, this ontological difference signifies more than the distinctiveness of agential realism compared to other interpretations of quantum mechanics. Any theory featuring collapse upon measurement faces the difficulty of explaining the collapse (or at least indicate when a collapse takes place and when contact between systems follows the unitary evolution given by the Schrödinger equation).<sup>38</sup>

However, in rejecting the reality of the wave function, there is no ontological collapse in relational quantum mechanics (see Dorato (2016, sec. 3.2) for a discussion). It is simply a brute fact in relational quantum mechanics that the quantum events follow the pattern specified by the quantum formalism (in a relative state formulation (Everett, 1957)).<sup>39</sup> Agential realism cannot help itself to a similar solution: The intra-actions within phenomena enact boundaries of system and measuring agency

<sup>38</sup> See Brown (2009) for a discussion of this issue in the context of relational quantum mechanics.

<sup>39</sup> While this leaves no contradiction in relational quantum mechanics, Laudisa (2019) argues that it is not explanatorily satisfactory to simply treat this evolution as a brute fact.

that produces determinate values for observables, but at the same time these two systems become (ontologically) entangled (though this is not explicit in the measurement and can only be measured by a new external measuring agency.) It is true, as Barad remarks, that the system “appears as a mixture if the degrees of freedom of the instruments are bracketed” (2007, p. 346), but this does not explain why a measurement finds one rather than another value associated with the eigenstates of the (improper) mixture. Rovelli’s strategy of relational values and states does nothing to resolve this issue.

On Rovelli’s view, there is no contradiction in assigning a determinate value to the phenomenon comprising of system,  $S$ , and observer,  $O$ ,—in Rovelli’s terms, a determinate value to  $S$  relative to  $O$ —and ascribing an entangled state to  $S + O$  relative to an external observer,  $P$ . This, however, provides no explanation why  $O$  finds a determinate value when Barad insists that  $S$  and  $O$  are not ontologically disentangled by the measurement. Barad can of course resort to Rovelli’s solution, but this would compromise the ontological relational holism that drives many of the other alleged consequences of agential realism detailed in Sect. 2. There might be other more subtle ways to address the measurement problem within the framework of agential realism, but if nothing else, the present discussion exposes the need to supplement the many explorations of uses of agential realism in interdisciplinary work with a study of how it fares when faced with the standard foundational questions of quantum mechanics. In the absence of such studies, even saying that agential realism is consistent with quantum mechanics involves a leap of faith.

## 6 Conclusion

As we have seen, Karen Barad’s invocation of Bohr’s view on quantum mechanics in support of her own agential realism is based on a substantial misreading of his philosophy. Apart from her ontological interpretation of Bohr’s use of the word “phenomena”, which does not correspond to Bohr’s epistemic usage, she also wrongly believes that Bohr wants to eliminate the epistemic distinctions between subject-object, knower-known, and word-world. Again, very little in Bohr’s writings backs such a claim. Although Barad is not the first writer who interprets Bohr as a realist, we have also seen that her realist interpretation is radical different from others’. With that said, Barad could be seen as following other recently influential interpretations of quantum mechanics such as QBism (e.g. Fuchs et al., 2014) that also draws inspiration from Bohr without, however, claiming that they represent Bohr’s actual views. This is consistent with Barad’s primary ambition to determine what “epistemological and ontological issues that quantum physics forces us to confront.” Nonetheless, there are interpretations of quantum mechanics whose epistemology and ontology are radically different from that of agential realism, Bohmian mechanics being an example. Barad’s interpretation is at best one among many interpretations of quantum mechanics. In other words, agential realism is not forced upon us by quantum mechanics despite the occasional impressions to the contrary in Barad’s writings. Moreover, even as an interpretation of quantum mechanics, agential realism has its challenges; especially in relation to the measurement problem where

further study is needed to assess whether the agential realist account of this problem is even coherent.

As social theorizing, Barad's ideas are profound, interesting, and thought provoking and we have not argued here that agential realism is without any merits. We have only argued that, if any, these do not stem from quantum mechanics.

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