Peter Baumann*

Not Just Many Worlds but Many Universes? A Problem for the Many Worlds View of Quantum Mechanics

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Abstract: The many-worlds view is one of the most discussed "interpretations" of quantum mechanics. As is well known, this view has some very controversial and much discussed aspects. This paper focuses on one particular problem arising from the combination of quantum mechanics with *Special Relativity*. It turns out that the ontology of the many-worlds view – the account of what there is and what branches of the universe exist – is relative to inertial frames. If one wants to avoid relativizing ontology, one has to argue either that there is an additional source of branching due to *Special Relativity* and thus additional branches or worlds. Or one has to argue that there are not only many worlds but also many universes (sets of worlds or world-branches); there is thus not only one tree of many world-branches but many frame-specific trees, a "forest" of many world-trees. The main problem here is how one can understand all or any of this.

Keywords: quantum mechanics, many-worlds-view, special relativity, multiverse, Everett

According to the many-worlds view of quantum mechanics (originating with Everett 1957, esp. the note on 459–460; see also, e.g., Albert 1994, ch. 6), under certain conditions ("measurement") a state of some system splits into different, causally isolated branches of the world.[1] For instance, an electron

1 It is controversial whether Everett himself accepted the idea of splittings into many worlds: see, e.g., Barrett (2012, 39–45). I won't go into this exegetical debate here nor into alternative interpretations or views of quantum mechanics nor into the many variations of the many worlds view. I will rather just discuss views which defend the idea of such splittings which seems to be the most widely shared interpretation of the many-worlds view these days (see, e.g., DeWitt 1970, 33, 34–35). – It does not matter for the discussion here whether branches or worlds are uncountable, countably infinite or finite; the points made below apply to all these versions equally. – I also won't go into topics connected to decoherence because the problem presented here arises independently from particular views about decoherence; discussing this would go beyond the topic of this paper.

***Corresponding author: Peter Baumann**, Department of Philosophy, Swarthmore College, 500 College Avenue, 19081, Swarthmore, PA, USA, E-mail: pbauman1@swarthmore.edu. https://orcid.org/0000-0003-0991-6288

might initially be in a superposition of two spin states (up and down), e.g.: $1/\sqrt{2}|\text{up}> + 1/\sqrt{2}|\text{down}>$. Upon measurement of that spin it is not the case that the wave function of the electron collapses (into either "up" or "down" but not both) but rather that the system (and with it, the world) splits into two different and causally isolated branches: one were the electron has an up-spin and one where the electron has a down-spin.

Many people find this view hard to swallow and implausible. I want to raise a problem here that might make the view appear even more extraordinary and even harder to accept. The implications of the view are more surprising than it might seem at first. The problem can be explained in more or less non-technical terms. I will focus on what I take to be one important, core idea about many worlds in quantum mechanics.

Let us call the (temporally extended) state between one splitting which brought about some state and the next splitting of that state an "elementary part of a branch" or shortly: a "part". According to the many-worlds view, we're in one branch, going through many different parts as time goes by; many splittings are going on all the time. Now consider two different measurements, each one on a different electron, and each one leading to a splitting (for the sake of simplicity, we can leave aside here what else is going on in the universe). Electron E1 is in a superposition (which it can be, given the many-worlds view) of up- and down-spin along the *x*-axis and is being measured for spin along that axis while electron E2 is in a superposition of right- and left-spin along the *z*-axis and is being measured for spin along that axis:

P0: E1a in up-down superposition; E2a in right-left superposition, or:

$$\{a|\text{up}_x>_{E1} + b|\text{down}_x>_{E1}\}\{c|\text{right}_z>_{E2} + d|\text{left}_z>_{E2}\}.$$

E1 and E2 are not entangled with each other. The measurement of E1, Mx, leads to a splitting into one branch with an up-spin for E1 and another branch with a down-spin for E1. The measurement of E2, Mz, leads to a splitting into one branch with a right-spin for E2 and one branch with a left-spin for E2. Let us assume for a moment that E1 and E2 share the same inertial system. If the measurement Mx happens first, then there is a time between measurements Mx and Mz during which there are 2 different parts, each of a different branch, P1 and P2. P1 contains a descendent of E1 (E1a) with an up-spin as well as a descendant of E2 (E2a) in a superposition between right-spin and left-spin. P2 contains a different descendant ("counterpart") of E1 (E1b) with a down-spin as well as a descendent of E2 (E2b) in a superposition between right-spin and left-spin (see below for the relation between the likes of E1, E1a, and E1b). Hence, we get the following situation after Mx and before Mz:

P1: E1a up; E2a in right-left superposition, or:

$$|up_x>_{E1a}\{c|right_z>_{E2a} + d|left_z>_{E2a}\};$$

P2: E1b down; E2b in right-left superposition, or:

$$|down_x>_{E1b}\{c|right_z>_{E2b} + d|left_z>_{E2b}\}.$$

After both Mx and Mz we get this (with descendants of the second degree for E1 and E2):

P3: E2aa right; E1aa up, or:

$$|right_z>_{E2aa}|up_x>_{E1aa};$$

P4: E2ab left; E1ab up, or:

$$|left_z>_{E2ab}|up_x>_{E1ab};$$

P5: E2ba right; E1ba down, or:

$$|right_z>_{E2ba}|down_x>_{E1ba};$$

P6: E2bb left; E1bb down, or:

$$|left_z>_{E2bb}|down_x>_{E1bb}.$$

However, if measurement Mz happens before Mx, then there is a time between these two measurements during which there are 2 different parts P7 and P8, each of a different branch. P7 contains a descendent of E2 (E2a) with a right-spin as well as a descendant of E1 (E1a) in a superposition of up- and down spin. P8 contains a different descendent (“counterpart”) of E2 (E2b) with a left-spin as well as a descendant of E1 in a superposition of up- and down-spin. So, after Mz and before Mx we get the following situation:

P7: E2a right; E1a in up-down superposition, or:

$$|right_z>_{E2a}\{a|up_x>_{E1a} + b|down_x>_{E1a}\};$$

P8: E2b left; E1b in up-down superposition, or:

$$|left_z>_{E2b}\{a|up_x>_{E1b} + b|down_x>_{E1b}\}.$$

After both Mz and Mx we get this:

P9: E1aa up; E2aa right, or:

$$|up_x>_{E1aa}|right_z>_{E2aa};$$

P10: E1ba up; E2ba left, or:

$$|up_x>_{E1ba}|left_z>_{E2ba};$$

P11: E1ab down; E2ab right, or:

$$|down_x>_{E1ab}|right_z>_{E2ab};$$

P12: E1bb down; E2bb left, or:

$$|down_x>_{E1bb}|left_z>_{E2bb}.$$

Finally, there is the case where Mx and Mz happen simultaneously. This results in 4 branches with different parts:

P13: E1a up; E2a right, or:

$$|up_x>_{E1a}|right_z>_{E2a};$$

P14: E1b up; E2b left, or:

$$|up_x>_{E1b}|left_z>_{E2b};$$

P15: E1c down; E2c right, or:

$$|down_x>_{E1c}|right_z>_{E2c};$$

P16: E1d down; E2d left, or:

$$|down_x>_{E1d}|left_z>_{E2d}.$$

We may assume for the sake of simplicity that both E1 and E2 have never before been and will never again be measured for spin along the *x*- or the *z*-axis. We can also leave the question open whether electrons have inter-branch/inter-part identity (e.g., E1a = E1b?) or intra-branch identity (e.g., E2a = E2aa?) – or whether we should rather accept talk about Lewisian counterparts in such cases (see

Lewis 1986). Whatever our choice with respect to these much discussed questions, the crucial point is that the above histories of the branching universe differ. The first but not the second contains P1 and P2 where E1 has developed into a definite state of up- or down-wards spin while E2 is right-left-superposed; the second but not the first contains P7 and P8 where E2 has developed into a definite state of right- or left-wards spin while E1 is up-down-wards-superposed. The third history contains neither of these parts. All three histories have an identical initial state P0. Their final states are qualitatively the same and one might wonder whether they could be even token-identical.

To illustrate:

World Tree A

(Mx before Mz)

```
       P0
       /\
      /  \
   P1     P2
   /\     /\
  /  \   /  \
P3   P4 P5   P6
```

World Tree B

(Mz before Mx)

```
        P0
        /\
       /  \
    P7      P8
    /\      /\
   /  \    /  \
P9  P10  P11  P12
```

World Tree C

(Mx simultaneous with Mz)

```
          P0
   /    |    |    \
 P13  P14   P15  P16
```

Now, what if E1 and E2 are located in different inertial systems? I am putting aside some basic and very difficult questions about the possible relation between quantum mechanics and relativity theory – for the sake of the following discussion. If one were unwilling to do so, then what follows could be seen as a further problem for their relation and their compatibility. If simultaneity and temporal order can, as we must assume, vary with and be relative to different inertial systems, then whether Mx or Mz came first or whether both were simultaneous might have no absolute answer (in the sense of an answer that doesn't relativize to inertial systems). People have learned to live with that – and quite well. But can one as well live with a relativity concerning which parts – P1 and P2 or rather P7 and P8 or even none of these–of the branching universe exist or don't exist? Can the truth of a statement of the form "Part so-and-so of branch such-and-such did exist at some point in the history of the universe" vary with inertial systems? Can we give up the idea of a non-relative ("absolute") view of what exists in the universe and its many branches or worlds and accept an "objective indeterminacy" concerning what parts and branches or words exist (see the pioneering Aharonov and Albert 1984, 228; also see the hint at this in Carroll 2019, 171 as well as the passage around it at 169–172; see also the remarks in Bricmont 2017, 128–131, 158 with special application to questions concerning causation)?[2]

One might want to argue that this problem already exists for *Special Relativity*. Consider two dice, X and Y, each of which shows a 6 at t-0. Then, X is thrown and shows a 3, and Y is thrown and shows a 5. If X is thrown at t-1 before Y is thrown at t-2, we get the following temporal series of sums of what the dice show: t-0: 12, t-1: 9; t-2: 8. If Y is thrown at t-1 before X is thrown at t-2, we get the following temporal series of sums of what the dice show: t-0: 12; t-1: 11; t-3: 8. However, the difference of sums at t-2 can be completely reduced to and explained by a difference in viewpoints from different inertial systems. Things are different for the many-words view: Here we get a deep ontological difference as to what worlds or branches exist. The viewpoint-difference in *Special Relativity* is turned into an ontological difference. Ontology gets relativized in a way that is not entailed by *Special Relativity*.

If one wants to avoid relativizing ontology to inertial frames, then one could redescribe what looks like frame-relativity rather as the existence of additional sets of branches or worlds. There would then be, according to this version of the view, two sources of the plurality of worlds. First, there is the familiar one, well-known from standard expositions of this view of quantum mechanics: Measurement and the lack of a collapse of the wave function leads to splitting and branching. Second, there is one due to *Special Relativity*: Different inertial systems create different sets of branching worlds. The many-world-view would not be motivated exclusively by quantum mechanics but also by *Special Relativity*. It is not obvious whether this is an advantage (of combining different theories) or a disadvantage (of making things much more complicated and creating additional theoretical tensions between the theories). Another question would be how any frame-specific set of branches relates to all the other branches. Consider the trees A, B and C above. They have the same origin in P0. Then they split or diverge depending on whether there was just one original state P0 or three different and overlapping tokens of the same type of P0. Difficult questions arise with respect

2 Following David Albert, one can call all this a violation or failure of narratability: "Call a world *narratable* if the entirety of what there is to say about it can be presented as a single *story*, if the entirety of what there is to say about it can be presented as a *single temporal sequence of instantaneous global physical situations*." (Albert 2015, 109).

to the end states of A, B and C. If they are token-identical, then we are either dealing with a fusion of A, B and C into just one state or with a convergence and resulting overlap of three qualitatively identical states. In the first case (the case of fusion), one would worry about the causal independence of different branches; it seems that this principle dear to the many-worlds view would be violated here (for instance, P1 in tree A is causally related to P3 in tree A which – if it is token-identical with P9 in tree B – is also causally related to states in tree B). In the second case (convergence and overlap), one would have to make plausible the idea that what looks like just one state is really and overlap of more than one and perhaps infinitely many overlapping, qualitatively identical states. Finally, if there are at least as many branches or worlds as reference frames, one should wonder how many reference frames there would be? As many as there are elementary particles? Even more? There is a threat of losing the idea of a world by getting too many of them.

Another way of avoiding a frame-relative ontology would be to go even further in a sense and add universes – sets of branches or worlds–and not just branches or worlds to what we took to be the one and only one universe. What there is, according to this idea, is not exactly one tree of branches or worlds but a forest of such trees. One might want to speak of a "many-worlds-within-many-universes" view, a many-universes or multiverse view rather than only a "many-worlds" view. And the word "universe" would have to be a plurale tantum. This would be another way of combining quantum mechanics with *Special Relativity*. One problem with this view is that even if we understand what a plurality of worlds could amount to, it is very hard to understand what a plurality of universes amounts to. It has been a very common thought that "[t]he world is everything that is the case" (Wittgenstein 1922, 1). According to the common many-worlds view under discussion here we should rather say that the universe is everything that is the case in the different worlds, or: everything that is the case is the universe of worlds. Given the last twist to the view under discussion we should rather say that everything that exists is the multiverse, all the universes (of worlds) taken together. Anxious minds might wonder at this point whether there is really just one such multiverse or whether the multiplication of ontological levels continues, perhaps even ad infinitum. Apart from that, the question above about the numerosity of frames of reference and thus also of universes will come up, too.

So much for three different options for an ontology of worlds when combining the many-worlds view with *Special Relativity*. Does it matter for all this whether branching is "global" or not? That branching is global means that "branching happens throughout the whole wave function whenever it happens anywhere. When the universal wave function splits into multiple distinct and effectively non-interacting parts, the entire world splits—along with every object and agent in it." (Sebens and Carroll 2018, 34). The above arguments works fine with the assumption of global branching. I have implicitly assumed global branching above – but only for the sake of ease of exposition. So, what about local branching, the idea that branching spreads out with a velocity <c (see, e.g., Wallace 2012, 306–311 and also Carroll 2019, 169–172 who seems to be fine with both views equally; see for this distinction also Wallace and Timpson 2010, 715–720 and Waegell and McQueen 2020, sec.5)? It seems, however, the same problem appears both before and after the light cones of the two particles overlap (apart from that, the two particles may be spatially quite close to each other). Finally, local branching as such doesn't question the idea that branches exist "absolutely", not just relative to inertial systems; it rather introduces some temporal asymmetries between branching events in different light cones but no differences as to which parts and branches exist and which don't exist. The problems and questions presented here do not presuppose that there are asymmetries due to different light cones. And they suggest that it is not just the branching structure that is frame-dependent but the existence of branches themselves (similar remarks apply, mutatis mutandis, to the inertial frame dependence Arntzenius 2014, 96–97 discusses).

One could try to find a way out of these problems by restricting oneself to non-relativist quantum mechanics. However, this comes with the prize of making the relation between special relativity and quantum mechanics even more burdened. Another strategy would be to embrace ontological relativization and use relational quantum mechanics (see, e.g., Laudisa and Rovelli 2019) as a way out here. It is captured in the following quote: "In quantum mechanics different observers may give different accounts of the same sequence of event" (Rovelli 1996, 1643) – where the different accounts can all be correct, though not mutually compatible.[3] "Observer" here means any physical system; the view gives up the idea of non-relational (to some observer) states. Perhaps then adherents of the many-worlds view should be "relationalists"? One can have doubts that the possible solution of our problem is a good enough reason to become a relationalist (rather than give up the many-worlds view).[4] The main problem discussed in this paper – the frame-dependence of branches and universe(s) – arises if one doesn't accept

3 Related is Fine's (2005) "fragmentalism" according to which reality is divided into mutually incompatible but internally maximally coherent "fragments". For its application to *Special Relativity* in particular see Fine (2005, 298–307).

4 Dieks (2019, 56–57) proposes perspectivalism as a solution to the "Wigner's friend" problem – which is not the problem discussed here. This perspectivalism would result in "local" splittings, given a many-worlds interpretation. However, Dieks prefers a single-world view to a many-worlds view (67–68).

relationalism or perspectivalism. It extends to any other view that aims at combining relativity with the many-worlds view.[5]

I have presented a problem and discussed three responses each of which lead to serious questions and problems. I don't take all this to constitute a refutation of the many-worlds view but rather a presentation of important questions and problems that the many-world view needs to deal with in order to be acceptable.

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5 It also does not help to argue that the individuation of branches and worlds can be legitimately more or less coarse- or fine-grained in different ways so that the question how many branches exist is indeterminate and has no meaningful answer (see, e.g., Wallace 2012, 99–102). The problem presented here arises for any given level of fine- or coarse-grained individuation and thus remains unaffected by the above indeterminacy.

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