Possibility, actuality, and the growth of imagination: The many-worlds approach to quantum physics

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Resumen. *Posibilidad, actualidad y el crecimiento de la imaginación: la física cuántica según la interpretación de los universos múltiples*

Las interpretaciónes de la física cuántica de Everett-DeWitt hablan de una multiplicidad de mundos físicamente coexistenrtes. Éstas imaginativas reacciones a los problemas conceptuales de la mecánica cuántica estándar forman una família de propuestas de "universos múltiples" (PMW en su siglas inglesas) que, sin pleno éxito, han sido tachadas de incoherentes.

Palabras clave:

Abstract

Everett-DeWitt interpretations of quantum physics speak of a multiplicity of physically coexisting worlds. These imaginative reactions to the conceptual problems of standard quantum mechanics form a family of physicalist "many-worlds" proposals (PMW for short) that have been variously dismissed as "incoherent", so far without full success. A renewed charge by Hilary Putnam now seems to pose deeper trouble for PMW. In a recent paper, he seizes on "Schrödinger's cat" situations to expose how PMW relativization of actuality and basic combinatorics jointly ruin probabilistic talk. Putnam focuses on confirmation and luck. His case against PMW is thought-provoking but also questionable, or so I suggest in this paper. First I argue that, as presented, Putnam's charge doesn't go through. I then consider his argument proper. According to Putnam, experimental DeWittians must count themselves as "lucky" in a seriously incoherent sense. I consider his take on "luck" and deny that defenders of PMW need to so regard themselves. Although extravagant, their position cannot be fruitfully dismissed as incoherent on metascientific grounds. Indeed it attests to the way science rationally helps the imagination to grow.

Key words: PMW, many-worlds

1. Introduction

Many-worlds interpretations regard the linear part of quantum mechanics as adequate for providing a complete dynamical representation of phenomena. In versions following DeWitt (1970), a measurement process physically "splits the world" in the sense of generally turning each of the various possible outcomes into a sub-state or "branch" of the total-world, the whole of physical reality comprising all such branches. In recent proposals of this variety (PMW for short), the "instantaneous collapse" of the wave function (ordinarily associated with measurements and such) is traced to a branch-rooted, branch-relative aspect of the phenomenon we call "awareness". From this perspective, our experience as *observers* connects us with only this or that branch out of many others which are just as real, and thus only to a tiny part of the total physical universe. To get a fuller picture one needs to work out the complete wave function in accordance to the linear part of quantum theory.

Since its inception, this way of understanding quantum mechanics has been variously faulted. Prominent among the critical issues raised are the need to specify a preferred basis for the branching of physical reality, conceptual issues about probabilities in quantum physics, also issues about the identity of worlds and persons over time, and about the relationship between human consciousness and its physical substratum. A related but more poignant objection denies that one can ever rationally come to believe PMW.

Although admittedly bizarre and initially very problematic, PMW has been much improved in recent decades. Unlike early versions of the many-worlds approach (Everett 1957, DeWitt 1970), the best current renditions no longer save the classical-like features of ordinary experience by smuggling them in "by hand"; nor do they embody an arbitrarily chosen basis for the total state (as Everett and DeWitt proposals did), but rather let all such features emerge naturally from seemingly reasonable claims about prevailing physical conditions and interactions. In the most cogent present submissions (for example, by W.H. Zurek, 1998), the position basis gets naturally picked up as special by the locality of regular physical interactions, a move helped by the phenomenon of decoherence, which also helps address some important issues regarding measurement, world-branching, probabilities, and identity:

(i) Interactions of a completely general sort turn initially independent systems (i.e. ones represented by initially factorizable joint states of composite observers and their environment) into entangled systems represented by complex quantum mechanical states made up of effectively orthogonal "branches". In the position basis, each component of those branches corresponds to an approximately classical world.
(ii) A quantum measurement is understood as a natural physical process in which a microscopic superposition is magnified (under the basic linear dynamics) up to a macroscopic scale. The general interactions involved in a measurement process spontaneously give rise

to different branches for each of the possible measurement outcomes.
(iii) The distribution of values that the quantum state links with "observable outcomes" turns out to satisfy the probability calculus to a remarkable high degree for magnitudes laying in the decoherence basis.
(iv) Relevant work in recent metaphysics is brought to bear on standing conceptual issues, particularly Derek Parfit (1984) on identity of persons and David Lewis (2004) on plurality of worlds.

And so, current MPW might seem entitled to taking the quantum algorithm as yielding probabilities, albeit in a revisionary, Everettian relational sense available within each decohering branch. However, to some radical critics current PMW leaves untouched some conceptual difficulties, which they find terminally problematic. According to Hilary Putnam, in particular, PMW interpretations are untenable because, he maintains, such proposals give up the distinction between actuality and possibility, and -he adds- once one gives up that distinction the notion of "probability" becomes *incoherent* (Putnam, 2005).

2. Putnam's probability argument

Consider the following "Schrödinger's Cat experiment". Imagine two light bulbs, one red and the other green, and suppose this is arranged so that either the red light goes on or the green light goes on when the interaction takes place (but not both). The probabilities may be unequal. Now let this experiment be performed many times. If, as PMW assumes, the world is relevantly governed by just the Schrödinger equation, in the course of the first trial the total state will go into a superposition of the form p (Green Light lights)+ (1-p) (Red Light lights), where p is the probability that the green light goes on and (1-p) is the probability that the red light goes on. On PMW that means there will be two physical universes, in one of which only the green light will be observed and in the second of which only the red light will be observed. Like earlier critics, Putnam thinks that the numbers p and (1 – p) cannot be understood as probabilities of the various particular outcomes actually occurring, because –he maintains - on PMW all the outcomes represented by branches with nonzero coefficients do materialize.

Putnam asks, "Why one doesn't see a superposition of red light on and green light on?" To which the PMW reply is: because the state vector p (Green Light)+ (1-p)(Red Light) is entangled with the observer's state vector in the peculiar quantum mechanical way. That is, after the interaction, two physical universes exist, each with its own "continuation" of the original observer. In the first universe the observer sees the green light flash, and in the second he sees the red light flash. Accordingly, once the first experiment is performed, the total physical reality will have be two observers, one seeing a green light and the other a red light. If the experiment is performed thirty times, at the end of the runs there will be a "super-world" comprising 2^{30} observers, along with 2^{30} distinct "branch-histories".

Putnam invites us to imagine himself as the person doing this experiment, and asks,

"What is the probability in the naive sense – not the 'probability' in the quantum mechanical sense, but the probability in the sense of the number of my future histories in which I will observe that, say, the green light went on half of the time plus or minus 5% of the time divided by the total number of my future histories?"

Simple combinatorial analysis reveals an answer that is independent of the quantum mechanical "probability". But now this independence raises a worry: Why should one use quantum mechanical "probability" to predict what is likely to be observed? If the coefficient p above is very small (something one can easily arrange for), then the histories in which Hilary Putnam confirms quantum mechanics will be exceedingly rare. But then, how come he is so lucky to have confirmed the theory? How come Putnam's observations have so far been in accordance with quantum mechanical probability?

We thus get the following serious complaint: "on the Many Worlds interpretation, *quantum mechanics is the first physical theory to predict that the observations of most observers will disconfirm the theory"* (Putnam 2005). The intended philosophical moral of this remark is quite worrying:

> *... once you give up the distinction between actuality and possibility – as the Many Worlds interpretation in effect does, by postulating that all the quantum mechanical possibilities are actualized, each in its own physical universe – once you say that all possible outcomes are, ontologically speaking, equally actual – the notion of `probability' loses all meaning*.

To Putnam, the idea of having no collapse and no hidden variables "is incoherent" (2005). But charges of incoherence notoriously depend on some claims being taken for granted on metaphysical grounds. This raises a big red flag on such charges.

My interest here is not to defend the plausibility of the PMW approach, let alone endorse it, but to spell out the suspicious character of quick dismissals of revisionary physics based on metaphysical or commonsensical strictures. In the case of PMW, I also wish to insist that its development attests to the way science rationally helps human imagination to grow.

3. A clarification

Putnam is of course right on relative numbers as dictated by combinatorics. In situations like his thought experiment, for a reasonable error allowance (say 5%) the neighborhood around the most probable outcome covers only a small fraction of the total number of possible cases. Since in PMW each possibility counts as one world, regardless of its relative amplitude in the total state, it follows that, for indefinitely many sorts of imaginable final states, in PMW the majority of observers should fail to confirm quantum mechanics. It thus turns out that PMW is far more at odds with ordinary ideas than generally realized, particularly regarding probabilities (about which our "natural" imagination is notoriously poor to begin with). Putnam is right regarding world numbers. However, I see several problems with his charge against PMW.

If physical reality is as PMW says, how come we are so lucky to confirm quantum mechanics? I wish to suggest some possible lines of reply on behalf of PMW.

Consider the issue of confirming quantum mechanics in the 2^{30} worlds involved in Putnam's thought experiment. At least as presented, the proposed experiment doesn't straightforwardly expose any interesting problems about the confirmation of quantum mechanics. The reason is simple: The likes of us are able to confirm quantum mechanics first and foremost because we are entities of a physical sort which encompasses very numerous distinctly quantum-mechanical processes. What we call "human observers" simply would not arise without quantum mechanics "working properly" on a rather massive scale. Indeed, for a person actually to *run* the 30 experiments in question, a very great deal of ordinary background physical regularity needs to be in place. Nobody could live (let alone act) in a world lacking that. My point, then, is that the description of Putnam's thought experiment already presupposes numerous regularities operating well enough -not least very many of a quantum mechanical sort. In the "weirdest" of the 2^{30} world branches considered by Putnam (the ones in which the light color outcomes depart the most from quantum mechanical expectation values), the experimental frequencies yielded would be highly deviant with respect to the expectation values for the experiment, but little else could be deviant (otherwise neither Putnam nor his equipment would be there at all). It follows that, at least as far as the specific thought experiment at hand is concerned, the incoherence charge fails: in their respective branches all 2^{30} Putnams are surrounded by available information that would allow them to confirm quantum mechanics rather splendidly, even if most of them may not do so through their particular series of "Schroedinger cat" experiments. To come to accept quantum mechanics, a person living in any of the deviant branches envisaged by Putnam might simply look at the rest of his relative-branch milieu. Corroborations of the quantum mechanical world would then come plentifully enough from thermodynamical, spectroscopic, radioactive phenomena and so forth -even raw qualitative phenomena (for example, the color of the sky on a sunny day) would provide strong hints in the "right direction".

4. On luck

But, of course, in an important way the above rejoinder is off the mark, for surely it leaves intact an important insight against PMW. If "most" world-histories are as utterly weird and inhospitable to physical humans as PMW dynamics appears to require, how come we are so lucky to find ourselves in such a "regular" history of the world after all?

Perhaps Putnam's deeper complaint is better construed as follows: out of all the myriads of actual histories envisaged in PMW, *the vast majority correspond to utterly weird environments in which no confirmation of quantum mechanics seems viable*. In such worlds not only there can be no Putnams -there can be no life as we know it. At this juncture the force of the complaint seems to shift to the issue of "luck", specifically to the question, "How come we are so lucky to live in one of the comparatively very few worlds that allow for the likes of stable planets, organic life and also us?"

But, isn't this an old non-problem? We may be lucky to be the way we are, given the myriads of "actual branches" existing in the total universe according to PMW. However, luck in this sense seems no different from that in which each of us -as individuals- can be said to be "lucky" in many other ways -to have been born, belong to a species that made it through natural selection, be part of a planet that had the right characteristics at the right time for our sort of chemically-based life to be, and so on. If this is correct, introducing this sense of luck into the PMW narrative involves no special conceptual problem (unless of course one wants to beg the question). Surely, confronted with the present worry, a PMW defender should bite the bullet and simply recognize that the type of relative-branch world in which "he" lodges fails to dominate in terms of relative numbers, but then insist that being thus "lucky" in no way renders incoherent his (otherwise weird) proposal. The point is that PMW cannot be dismissed as incoherent merely because of basic combinatorics and the relativization of actuality PMW involves. All that needs to be admitted is that, in the suggested way, PMW is simply furthering the clash of physics with certain cherished beliefs -for example that the universe is made for us, revolves around us -the sort of place where the likes of us are to be expected as a matter of some kind of "ontological entitlement". It is not accidental that in his seminal article Everett likened his approach to that of Copernicus, an early scientist renowned for having tamed our natural sense of self-centeredness. Now PMW further spoils old intuitions in that direction, and a great deal more radically. Not necessarily a bad thing.

5. Rational action

There is no denying that in PMW the vast majority of world histories are utterly bizarre. Still, if PMW is basically correct, then in every "ordinary" history, people in it would be right to expect future to unfold in a manner close enough to the probabilistic, quantum-mechanically "normal" way. And yet, to return to Putnam's stance, what can this *mean* once the distinction between possibility and actuality is obliterated a-la-PMW? A different level of response seems to be called for here.

One reply, in the spirit of Deutsch (1998), may run as follows: DeWittian denizens experience genuine uncertainty. In a measurement operation, between the time decoherence has done its work and the time the experimenter looks at the result, he is in an authentic state of uncertainty as to which of the expected successor branches he will find himself in. During this interval the experimenter knows that his successors form an indexed family (corresponding to the possible outcomes), but he doesn't know which particular index he's got. Suppose, then, that this experimenter carries on numerous measurements in which during the noted periods of uncertainty he also bets on outcomes; and suppose further that he corroborates that the best betting strategy follows the quantum algorithm (that is, he confirms quantum mechanics). If so, he would know from experience that his aims are generally better achieved when he follows quantum mechanics than when he does not. That is, he corroborates that guiding his actions by the relevant quantum mechanical probabilities optimizes his gains. This reply seemingly matches the standard rationale for reading normalized quantum mechanical intensities as probabilities: one uses recorded frequencies to estimate "probabilities", finds them in agreement with the quantum algorithm, and then prepares for the future accordingly. To this educated experimenter, in any branch history that extends long enough in time, the numbers yielded by the quantum algorithm are ratified both as objective frequencies and as basis for rational decision.

But Putnam could reject the above move. If both PMW and the finitude of accessible branch histories are taken seriously, then every "possible" finite historical succession will be realized anyway. So, what "rational plans" can a PMW believer make regarding world outcomes?

Enlightened by quantum mechanics, a PMW believer can influence his successor branches to this extent: in many situations he is able fix which of the successor branches of his present world will have the largest amplitude. Still, Putnam may disallow this response as irrelevant –for, why would a sensible person take comfort in such a practice in a universe in which all the contemplated possibilities are bound to be "equally actualized"?

This connects with a methodological issue, already encountered in this paper, about being "lucky" too many times in a row. According to Putnam, our PMW advocate is lucky against the odds because of the generally low ratio of the number of high-amplitude branches relative to the total number of "equally real" branches out there. But notice the problematic character of the two key notions of number and equality played with here.

How many DeWittian branches are there in a given situation? The standard assumption takes this number to be equal to the number of possible outcomes, which is correct enough in many contexts. However, if branches are a byproduct of decoherence, then in general their number is *not a quantity really well-defined*. At any given time the number of branches equals that of the state components of the decoherence-preferred basis with nonzero coefficient in the total state. But this spells out trouble in at least two ways. First, many of the best candidates for preferred basis (conspicuously position) correspond to continuous quantities. The obvious move to meet this problem is coarse-graining, but this makes for a second source of trouble, as coarse-graining introduces an epistemic aspect into the picture. Partitions coarser than ordinary levels of precision will blur the state of macroscopic systems (which will thus get poorly modeled), while partitions that are much too refined will give rise to interfering adjacent branches (which will thus fail to qualify as representing "worlds"). Determining the "right" level of coarse-graining requires judgment involving some degree of arbitrariness.

At this point one may refuse to indulge in metaphysical revisionism, accept Putnam's objection, and hold on to an essentialist position about probabilities. Alternatively, one may opt for conceptual revisionism and challenge some received assumptions about objective probabilities, particularly some which seem not nearly as compellingly motivated as generally supposed. One such assumption is that probabilities are essentially tied to the Kolmogorov conception (as opposed to the weaker claim that probabilities are modeled only approximately by the said conception). Equally questionable seems the rejection of the noted kind of uncertainty at the end of measurement operations as grounds for a "bottom-up" approach to probabilities. DeWittians may not quite end up with the standard concept, but surely theirs would be a critical generalization of the initial concept, indeed one focused on probability's old link with *rational action*.

But, to repeat, how might quantum theory guide rational action if all the options one is meant to choose from are bound to be realized? What good can result from striving to reduce the quantum intensity of unwanted branches?

Here a MPW defender might seize on quantum intensities and try to appeal to their *physicality*. One option Vaidman (1998 & 2002) would be to regard quantum intensities as a measure of *existence*. I think this can be made compelling by explicitly introducing an element from Plato's Natural philosophy, namely the notion that "being real" admits of degrees. The stress should be on the idea that that it is intensity that makes a branch actual, indeed that intensity gives a branch *ontic weight*. A related, seemingly complementary move, would be to interpret properly normalized intensities as giving the *relative proportions* for the actual branches in place (intensity ratios being much better defined than "number of branches"). From this latter perspective, when the intensity of a given post-measurement total state is highly concentrated around the particular branch associated with outcome α, then the universe will contain massively more worlds in which the outcome is α. The suggested notions of "ontic weight" and "relative proportions" may be embedded in Deutsch's radical proposal, that for each world or branch of the total state there is a continuous infinity of identical worlds.

The important point here is that, it seems, a PMW follower has available twin critical generalizations of the notions of "probability" and "number of worlds". The generalizations in question take the relative intensity of any given branch as corresponding to the relative frequency of the world represented by that branch in the totality of many worlds. On this more intrepid PMW, the ratio of quantum mechanically "deviant" to quantum mechanically "correct" branch-worlds would be minute, thus rendering unsurprising that we should find ourselves in a branch where quantum mechanics turns out to be confirmable. PMW followers would be left with a weird revision of metaphysics, one advanced in response to the conceptual challenges posed by their weird picture of the physical world. All very bizarre, of course, but not bizarre enough to sustain a serious charge of incoherence.

And so, in light of all the above considerations, I think Putnam's incoherence charge against PMW, though clever, must be declared premature. The argument he provides does not expose terrible incoherence in PMW so much as additional "paradox" beyond the load carried by less extravagant versions of quantum mechanics.

The universe described by PMW is weird relative to our natural intuitions. The vast majority of the myriads of indiscernible partial world histories that, according to PMW, make up the universe do not contain the kind of structure needed to potentially confirm the theory by present scientific standards. However, in terms of “numbers”, the exact reverse is true, at least on the suggested ontic interpretation of branch numbers and branch intensities. The main point is that none of the troubles spotted in connection with PMW, by themselves, render PMW incoherent the way Putnam suggests. Nor does it warrant one to claim that in PMW the notion of probability is bound to "lose all meaning". To repeat, the concept of probability can be turned empirical by science. In particular, one can maintain that all the quantum mechanical possibilities are actualized, yet further assert that revised, more general concepts of actuality, “physical number” and probability are now in place. Such a defense could do this by taking the actuality of individual world histories to be "unequal" in a new, distinctly quantum mechanical way -by taking the quantum amplitude as a measure of ontic "weight". This aspect of the world would be epistemically accessible only within a fraction of the myriads of distinct finite world histories that constitute the Universe (according to PMW). It would be in those branches, and presumably those branches only, that being both alive and thinking is possible.

Finally a brief comment on the way science keeps opening and expanding the human mind. As I have insisted on previous papers in this series, many views that had long seemed "completely impossible" to hold are now scientifically well-established. As science gets more comprehensive and sophisticated, it looks as though its role as expediter of the growth of the human imagination, indeed the human mind, has only just begun. The development of PMW, I suggest, matters because it attests to this process of growth.

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