TOTALITY AND PHYSICS

by

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Abstract

This thesis argues that there is no sense to the idea of an absolutely general physical domain, a view I call *physical anti-absolutism*. Whilst there are reasons from the logic and metaphysics of totality to cast doubt upon the notion of totality, notably via Cantorian diagonal arguments and Russell's paradox, these results have hitherto had little influence on the physics of totality—the nature of totality as viewed from our best physical theories. The totality of all physical things, we are told—from loose change to distant galaxies—does comprise an absolutely general domain. After all, the *universe* is the whole world, the totality of all things, complete; literally, *turned into one*. How could it be otherwise? If there are entities which lie beyond the total, the total must subsume those entities too; totality never fails to include. Extant discussion in both metaphysics and physics has typically failed to connect the absolutely general domain as viewed by the metaphysician and logician with the absolutely general domain as viewed by the physicist. My aim is to bridge this gap, suggesting why we should consider logical results and metaphysical ideas to apply in the physical setting too. I propose that there are reasons from the physics of Newtonian mechanics, Einstein's relativistic theories and quantum mechanics to think that that one can always add more to a particular ontology, and thus there is no sense to the idea of an all-inclusive *physical* domain.

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A curious thing about the ontological problem is its simplicity. It can be put in three Anglo-Saxon monosyllables: “What is there?” It can be answered, moreover, in a word—“Everything”—and everyone will accept this answer as true.

Willard V. Quine (1948).

Introduction

This thesis argues that there is no sense to the idea of an absolutely general physical domain, a view I call *physical anti-absolutism*.[1] Whilst there are reasons from the logic and metaphysics of totality to cast doubt upon the notion of totality, notably via Cantorian diagonal arguments (§2.1) and Russell's paradox (§2.2), these results have hitherto had little influence on the physics of totality—the nature of totality as viewed from our best physical theories. The totality of all physical things, we are told—from loose change to distant galaxies—does comprise an absolutely general domain. After all, the *universe* is the whole world, the totality of all things, complete; literally, *turned into one*. How could it be otherwise? If there are entities which lie beyond the total, the total must subsume those entities too; totality never fails to include.

Extant discussion in both metaphysics and physics has typically failed to connect the absolutely general domain as viewed by the metaphysician and logician with the absolutely general domain as viewed by the physicist. My aim is to bridge this gap, suggesting why we should consider logical results and metaphysical ideas to apply in the physical setting too. I propose that there are reasons from the physics of Newtonian mechanics, Einstein's relativistic theories and quantum mechanics to think that that one can always add more to a particular ontology, and thus there is no sense to the idea of an all-inclusive *physical* domain.

Patrick Grim's (1991) *The Incomplete Universe* is comparable in a number of ways, considering the metaphysical and epistemological implications of results in logic to teach lessons about knowledge and truth. Similarly, Agustín Rayo (2019; 2022; Rayo & Uzquiano 2006) argues that there is no sense to the idea of an absolutely general domain as viewed by the metaphysician. Crucially however, and contrary to the arguments put forward here, such views make little comment on physics. In fact, Rayo (2022, p.3) gives us reason to think that his views might not apply to the physical domain at all: "If the "absolutely general" domain were taken to consist entirely of physical objects, a good answer might not be so hard to find, since it might be grounded in, e.g. the number of particles created in the Big Bang."

Recent work in philosophy of physics, most notably by Jenann Ismael (2019) convincingly proposes the impossibility of a point from which all comes into view (such as a Laplacean

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[1] That "there is no sense to the idea of an absolutely general domain" is an expression attributed to Rayo (2022). Sometimes I suggest that "the notion of an absolutely general domain is incoherent". I consider these expressions to be interchangeable.

intelligence).[2] Moreover, Cuffaro and Hartmann (2021), writing in response to the well-established orthodoxy of the *closed systems view*, propose the *open systems view* in which quantum systems interacting with their environment are considered to be fundamental, motivating the thought that neither the concept of an open or a closed system is adequate for modelling the (non-unitary) evolution of the cosmos. Whilst Cuffaro and Hartmann make a compelling case for the physics of the open systems view, they reserve relatively few words for the metaphysical implications of their position. This project aims to bring relevant ideas from both physics and metaphysics to advance scepticism about the coherence of the notion of totality in accordance with our best physical theories.

The first step towards such a goal is to consider the nature of a physical theory (chapter 1). One way to do this is to analyse *how* or *in what way* a physical theory aims to describe the world. There are many ways in which a theory makes sense of a realm of phenomena, but it appears a theory's success can vary according to the descriptive techniques it adopts. This is an idea central to Einstein's distinction between principle and constructive theories: constructive theories describe phenomena by appeal to mechanistic processes inherent in layers of causal structure; complex phenomena can be built from entities proposed within an initial formal scheme. Principle theories on the other hand start with empirical rather than hypothetical facts, making use of general characteristics or *principles* that successfully predict the behaviour of a given phenomena.

Constructive theories are typically considered to be more explanatorily fundamental than principle theories. In the second half of the chapter, I analyse the accounts of Acuna (2016) and Van Camp (2011) amongst others to suggest that a broadly reductionist account of physics informs what they take to be the most effective way to discern the distinction between principle and constructive theories. By considering some alternative pictures of fundamentality (*infinite descent*, *cosmic void*, *monism*, *middleism*), I offer reasons why more unorthodox accounts of fundamentality may produce more challenges for those who hope to retain the distinction between principle and constructive theories and the proposal that constructive theories are more explanatorily fundamental. Clarifying particular ways that a physical theory's ontology can be formulated and the motivations for thinking such an ontology should be characterized in a particular way facilitates a full evaluation of the metaphysics and physics of totality, which is the focus of chapter 2 and 3 respectively.

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[2] In contrast to most, Ismael engages thoroughly with both the physics and metaphysics (2016, 2019) to advocate scepticism about the notion of totality and its place in physics.

After setting up relevant material in the logic of totality to motivate scepticism about the notion of an absolutely general domain, I introduce the (anti-absolutist) metaphysics of Rayo (2019, 2022) which challenges the thesis of absolutism by considering the role of language and its relation to the world it describes. Here, the anti-absolutist claims that "there is no sense to be made of a *language-transcendent domain*" (Rayo 2022 p.10. Original emphasis). That is, the notion of a metaphysically significant "articulation of the world into constituents" is incoherent. Whilst it may be true that there are electrons or hydrogen atoms, the particular descriptions we use to identify the relevant feature of the world have no *metaphysical* significance. "There is nothing about the world *as it is in itself*"—to borrow Rayo's (2022, p.28) phrase—that settles whether the distinction between the world containing electrons and the world not containing electrons is a correct one. Such distinctions are not distinctions inherent in the way the world is which is independent of the representational practices used to describe such features. Instead, since these distinctions are so useful, they are desirable as descriptions of the world.[3] If one accepts that an ontology is delivered by considering language's relation to the world it represents, one can appeal to the logical results of chapter 2 (Russell's paradox) to argue that for any given collection of objects within one's ontology, one can always use that collection to characterize more—thus motivating a view which doubts that the notion of an absolutely general domain (totality) is coherent.

The *physics of totality* (chapter 4) explores the relevance of the logic of totality and the metaphysics of totality in the context of physical theories. In Newtonian, relativistic, and quantum settings, I aim to show that without a totality fact that specifies that a given collection of events is *all* there is, the collection of events is left unspecified and there is no way to fix the total state. Given the total state can never be specified, I propose that in each of these domains there is no sense to the idea of an all-inclusive *physical* domain. In the quantum setting, a recent proposal by Cuffaro and Hartmann (2021) helps us understand the physics of open and closed systems. Whilst there has been considerable empirical success in formulating quantum theory in accordance with the view that closed systems are fundamental, an alternative approach is to say: the systems that we apply quantum theory to are open systems (even if the environment's influence on a quantum system is negligible, it is still an open system). Given one can formally represent quantum systems under a view in which open systems are taken to be fundamental,

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[3] This way of carving up the world plays a significant role in my reading of Everettian quantum mechanics (chapter 5).

and that all quantum systems are open systems[4], there is reason to doubt that the closed systems view is the preferred metaphysical description of reality.

The most obvious candidate for a closed system (and the most fundamental according to *monism*, detailed in §1.7) is the universe itself. Cuffaro and Hartmann (2021, p.46) make no commitment to whether the universe as a whole is a coherent notion (and whether it is open or closed), since if quantum theory is understood in accordance with the view that open systems are fundamental, "the ontological distinction between open and closed systems breaks down" *when describing the universe as a whole*. The lesson, they suggest, is a reminder that not every mathematical concept in our ontological investigation will line up with those pre-theoretic concepts we have about the universe. Whilst the authors remain silent about the coherence of the universe as a whole,[5] my suggestion is to deny that the *universe as a whole* is a coherent notion, an idea which is considered in detail through the application of Everettian quantum mechanics in chapter 5.

Before doing so, I assess how we should think about the idea of an objective, *quantum* world (chapter 4). Citing the interpretation of quantum mechanics literature specifically[6], antirealists (sometimes *operationalists* or *instrumentalists* and often associated with authors such as Bohr, Heisenberg and Dirac) purportedly abandon aspirations to describe an observer-independent reality and instead offer an algorithm for predicting the results of quantum measurements[7]. Realists on the other hand (often associated with the views of Everett, Bohm and Bell) suggest that theoretical claims refer to knowledge about the world, namely descriptions of a mind-independent reality. In reality, such a split isn't so clean, but this bears no weight in my proposal, namely that extant discussions about (anti)realism fail to consider the problems in stabilizing totality (the universe as a whole) as an object of knowledge.

This is illuminated most forcefully in §4.2-§4.3 in which I assess the claim that realist interpretations of quantum theory read the quantum state *literally* or relatedly, the claim that the quantum state represents reality *directly*. A *literal* reading of the quantum state, or the quantum state representing reality *directly* may be understood as claims that seek to represent reality or represent the world "*as it is in itself*". That is, if the wavefunction is successful in representing reality directly, then there is a particular account of the world, an objective fact that the

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[4] Apart from (arguably) the universe as a whole - see §5.1-§5.2 for details.

[5] Cuffaro and Hartmann (2021, §5.3).

[6] I discuss only those realist and antirealist views associated with the interpretation of quantum mechanics rather than appealing to the more extensive general philosophy of science literature on (anti)realism.

[7] See e.g., Ney and Albert 2013, pp.14-15.

representation correctly picks out. This is precisely the view that chapter 2 seeks to reject; a literal or direct representation of reality—it would seem—assumes that there *is* such a thing as an ontology that is distinct from the methods used to represent the world. *Physical anti-absolutism* denies that there is a description of the world, which is "metaphysically significant"[8], instead suggesting that the distinction between there being a quantum state or not is a theoretical tool that is made fruitful by its consistency with our observations about the world, and its usefulness as a particular description of reality. I conclude chapter 4 by considering how such a view of reality is situated within debates about (anti)realism.

Chapter 5 uses Everettian quantum mechanics (EQM) as a case study for the ideas raised in chapters 2-4. In the first half of the chapter, I take up where Cuffaro and Hartmann leave off by exploring some metaphysical consequences of their aforementioned *open systems view* (§3.8), with particular attention paid to the branching of Everett worlds. In the latter half, I argue that the standard account of world number in EQM is unsatisfying, offering a more explanatory account by appealing to two different modes of Everett world representation, the *immanent representation* and the *fundamental representation*. This motivates a view (consistent with physical anti-absolutism) which denies there is a metaphysical fact about the number of Everett worlds which is over and above our representational resources. Given this metaphysical reading, there is simply no fact available that allows one to specify that there are in fact *no more worlds*; the number of worlds in EQM is incomplete.

Chapters 6 and 7 are more digressive. Chapter 6 gives a concise analysis of *nothingness* by contrast to the notion of totality. If we take seriously those arguments that point to the incoherence of an absolutely general physical domain, then *nothingness* is also unattainable since one can never coherently speak of the domain that is purportedly emptied of all objects.

Finally, in further development of the view that there is no single, privileged description that will tell us whether a distinction in the world is *objectively* the case, I propose that those who endorse the Parfittian fission analogy (however implicitly) in discussions of EQM end up presupposing a privileged metaphysical description—but this is a mistake. In identifying a number of disanalogies between Everettian branching and Parfittian fission, I suggest that Everettians are doing themselves a disservice when they seek to employ arguments by analogy from fission cases.

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[8] Rayo (2022, p.27).

1. The Nature of a Physical Theory

This chapter aims to illuminate the ways in which particular metaphysical and physical theories carve up the world. There are very few physical theories (if any) that successfully bridge the gap between the representations of the physical theory and the world the theory represents. For one to explain a realm of phenomena, there are—more often than not—multiple methods available to generate an explanatory account of a given system. The method we choose is often hostage to the constitutive or regulative principles[1] in place prior to interpreting a theory. The metaphysics of fundamentality (§1.4-§1.8) and our categorization of theory-type (§1.1), for example, has a significant impact on how we understand physical theories to explain the world, and it is in virtue of assumptions such as these which motivates an articulation of the world in accordance with a particular ontology. This chapter opens the doors to a full evaluation of the metaphysics and physics of totality; it attempts to understand how a physical theory relates to the world and considers the effects of metaphysical presuppositions central to explanations of physical phenomena.

1.1 The Distinction between Principle and Constructive Theories

Einstein first proposed the distinction between *principle* theories and *constructive* theories in a short article in 1919[2]:

> We can distinguish various kinds of physical theories in physics. Most of them are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out. Thus the kinetic theory of gases seeks to reduce mechanical, thermal, and diffusional processes to movements of molecules—i.e., to build them up out of the hypothesis of molecular motion. When we say that we have succeeded in understanding a group of natural processes, we invariably mean that a constructive theory has been found which covers the processes in question.
>
> Along with this most important class of theories there exists a second, which I will call "principle-theories." These employ the analytic, not the synthetic, method. The elements which form their basis and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which the separate processes or the theoretical representations of them have to satisfy. Thus the science of thermodynamics seeks by analytical means to deduce necessary conditions, which separate events have to satisfy, from the universally experienced fact that perpetual motion is impossible.

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[1] See Friedman (1992) for a helpful analysis of constitutive and regulative principles.

[2] Einstein (1919, p.1). Reprinted under the title 'What is the theory of relativity?' in Einstein (1954).

> The advantages of the constructive theory are completeness, adaptability, and clearness, those of the principle theory are logical perfection and security of the foundations.
>
> The theory of relativity belongs to the latter class.

In addition to the "universally experienced fact that perpetual motion is impossible", Einstein also gives the principle of relativity, and Galileo's law of inertia (Einstein 1936, p. 307) as examples of physical *principles*, and thermodynamics, special relativity and general relativity as paradigm principle *theories*. One of the most perspicuous modern examples of a principle theory in the quantum domain is those who aim to construct quantum theory via information-theoretic principles. For example, Zeilinger (1999)[3] proposes an information-theoretic foundational principle for quantum theory, which fulfils a role similar to the principle of relativity (special relativity) or the equivalence principle (general relativity) and suggests an explanation for both quantum entanglement and the apparent randomness of quantum measurement. Similarly, Clifton *et al* (2003) propose an account according to which quantum mechanics is understood as a *principle theory*, the principles of which are information-theoretic. (See Timpson 2013, ch.8 for objections to the view).[4]

Flores (1999) identifies three distinctions between principle and constructive theories: firstly, there is an *ontological* distinction between the existence of *entities* postulated by constructive theories and the existence of general physical principles postulated by principle theories.

The epistemological distinction between principle and constructive theories concerns how one comes to know the existence of such features. For principle theories, Einstein (1914, p. 221) suggests, that “the scientist has to worm these general principles out of nature by perceiving in comprehensive complexes of empirical facts certain general features which permit of precise formulation”. Relatedly, Einstein (1905, p.38) describes the process of “raising” empirical generalizations “to the status of a postulate”, an example of which is given: “as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good”.

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[3] See also Brukner and Zeilinger (1999); Brukner and Zeilinger (2003).

[4] It’s also worth noting that in the philosophy of science, there is also a rich and extensive defence of various forms of *structural realism*. Notably, *ontic structural realism* appears in different forms (Ladyman 1998, French and Ladyman 2003, Ladyman and Ross 2007 and French 2014) advocating that *there are no objects*. In contrast to those who take laws and symmetries to be underpinned by an ontology of property-bearing objects, the *ontic structural realist* understands those laws and symmetries to be features of the ontological structure of the world—objects are eliminated from the fundamental ontology. This is an example of a metaphysical picture which may motivate the view that principles are explanatorily (and even ontically) more fundamental—an idea I return to in §1.4-§1.9.

Subsequently, he writes, "we will raise this conjecture (the purport of which will hereafter be called the 'Principle of Relativity') to the status of a postulate".

Einstein is comparatively quiet on how one comes to know the “hypothetically constructed” constituents of a constructive theory. For Flores, their hypothetical status has two salient features, however. Firstly, their inclusion in a theory prompts no commitment to antirealism since their existence is not at stake. Secondly, classifying constituents as hypothetical does nothing to prevent their existence *eventually* being confirmed.[5]

Postulating entities for constructive theories in this way can be fruitful, since such hypothetical constituents may (eventually) describe an objective feature(s) of a physical system. Flores’ example is molecules in the kinetic theory of gases: the experimental success in determining Avogadro’s number and molecule size give us reason to amend the status of molecules from hypothetical to *real*.

Finally, principle and constructive theories are distinguished by their function, playing different *conceptual* roles. For principle theories, a conjecture that is “raise(d)…to the status of a postulate” is a condition that all physical systems must satisfy. And so if the observations of physical phenomena appear to violate a postulate, one first looks for errors in the theoretical descriptions of relevant physical systems which may account for the apparent violation of the postulate. Consider the proposal that the total energy of physical processes is conserved. Once this conjecture is considered a postulate then any physical phenomena which appears to violate this postulate is regarded (first and foremost) as a failure in our descriptions of the relevant physical systems—either the descriptions are incorrect, or one has failed to account for a physical system which is relevant to the process. In other words, if a particular description of a physical system suggests energy is not conserved, the next step is to find out where the “lost energy” lies, rather than consider the physical system to be an example in which the postulate is violated.[6]

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[5] This method is echoed in Maudlin’s (2013, p.142) argument for a *primary ontology* (sometimes called *primitive ontology*) in a physical theory: “…postulation of something as a Primary Observable is itself a sort of theoretical act and may turn out to be wrong. But methodologically, it is desirable for the Primary Observables to be couched in a theoretically neutral language, that is, for the Primary Observables to be the sorts of things that competing theories will tend to hold in common.”

[6] Flores (1999) offers no comment on how these distinctions relate to one another. Although I make no commitment to the following view, one may speculate that the ontological distinction bears the most weight since the formulation of the epistemological and conceptual distinctions appear to make use of the ontological difference between principle and constructive theories.

1.2 Principle Theories and Constitutive Principles

Friedman (1992, p.73) gives a helpful way to understand Kant's distinction between regulative and constitutive principles noting its context within Kant's faculty of reason and faculty of understanding. Understanding is "constitutive of the possibility of experience", Friedman writes, "…experience must conform to the concepts and principles of the understanding, which, accordingly, are necessarily realized or instantiated in experience".

The relation between the faculty of reason and experience is *regulative*. In other words, the concepts of reason are not "realized or instantiated in experience", but do however play a pivotal role in guiding one's empirical enquiry into the objects of experience.[7] Such concepts do not reveal the composition or character of particular objects but reveal, "how we…are to *seek* the constitution and connection of the objects of experience in general".[8] Regulative concepts and principles present us with a heuristic; a perpetual pursuit of empirical enquiry, whose "ideal terminus…can only be approached asymptotically".

For Kant, the constitutive parts of Newtonian physics were the three Newtonian laws of motion and Euclidean geometry; these parts have a very different status to the empirical parts of the theory, such as the law of gravitation. The former constitutes the *conditions of possibility* for the latter. Kant mistakenly took these conditions of possibility for Newtonian physics to be necessary and true conditions for all future empirical science. Riemannian geometry and Einstein's relativity theories most notably give us good reason to reject this claim (see Friedman 2001, p.77).

Friedman's research (1992, 2001, 2008, 2010, 2012) has been central to a recent revival of Kantian philosophy of science. According to Friedman, a defining feature of both Newtonian physics and Einstein's relativity theories is a *constitutive function*; that which makes the mathematical formulation and the empirical application of theories to be first possible. This is evident in Einstein's revolutionary interpretation of Lorentz transformations. These transformations were not just understood as representing particular dynamical properties of electromagnetic objects moving relative to the aether but rather as constitutive of the "*geometrical-kinematical*"[9] framework of Minkowski spacetime. Rather than interpreting Lorentz transformations as empirical (dynamical) laws that governed electro-magnetic force, Einstein understood these transformations

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[7] Examples for Friedman (2010, p.73) include the concept of a deity, or, rather aptly, the "idea of the world as a complete totality".

[8] A670-671/B698-699

[9] Friedman (2001, p.62).

as geometrical-kinematical constitutive principles that reveals a spacetime structure that differs radically from previous scientific descriptions—a spacetime structure, which as Friedman (2001, p.62) notes, is incoherent according to classical physics[10].

The salient point is *how* such a revolutionary move was itself possible. Geometry functions as a constitutive framework, whilst the *choice* of geometry is an empirical one—there is no single, metaphysically privileged geometrical-kinematical framework. The three-plus-one spacetime structure of classical physics may be seen as a limiting case of the four-dimensional spatio-temporal structure of special relativity. Moreover, Euclidean geometry is a (finite) limiting case of the Riemannian geometry of general relativity. A constitutive principle may be understood as an approximation of a more general and more adequate *ideal* (governed by what *regulative* principles). The governing regulative principle dictates the *space of possibilities* for the sequence of successive constitutive principles.

Returning to the distinction between principle and constructive theories, a principle theory certainly provides the conceptual framework for a constructive theory to evolve but prior to that, a *constitutive principle* provides the conceptual framework for a principle theory to evolve. A principle theory may have a constitutive role but that isn't something the principle theory itself has established; it is something the principle theory inherits from the constitutive principle that forms the set of principles required for the principle theory to manifest in the first place. In the following section, I address the constitutive principles of the distinction between principle and constructive theories.

1.2 Constitutive Principles of the Distinction Between Principle and Constructive Theories

Flores' (1999) focus is to relate the two levels of physical theory-type (namely, principle and constructive) to theoretical explanations in physics—the "bottom-up" view of Salmon (1989) and the "top-down" view of Kitcher (1989). My concern here is to consider the principles required for the principle/constructive theory distinction itself to be established. Something about the behaviour of physical systems has led to the insight that a distinction of this sort is a helpful

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[10] For example, if time is absolute as Newton proposed, then the notion of relativity of simultaneity is incoherent since one appeals to the relevant reference frames in describing whether two events are simultaneous—and not to a system of absolute time.

way to categorise physical theories. How then can we account for the applicability of the principle/constructive theory distinction?

Whilst it was the domain of physics that spawned the idea, the principle/constructive theory distinction is a distinction that can bear fruit in a lot of places, more specifically in any place where we have a descriptive theory, perhaps most obviously in the special sciences (see e.g., McGann and Speelman 2020 for an account of its usefulness in psychological research). It's an idea that is interesting beyond the domain of physics. I then take its applicability to other domains to motivate the application of the distinction to the theories themselves, namely to analyse the nature of principle and constructive theories in view of the principle/constructive theory distinction. As I argue in chapters 2 and 3, there are reasons to think that there is nothing about the world "*as it is in itself*"[11] that settles whether the entities proposed by a constructive theory are *objectively* or *metaphysically* "correct"; rather a theory's ontology is directly related to our representational practices. One should thus be open to exploring the set of principles which motivate a theory to be categorised as entity realism or nomological realism, and consider the extent to which a theory's ontology is in fact singled out independently of the methods used to represent the world. The distinction between principle theories and constructive theories, I suggest, is part of a higher-order, *methodological* principle theory that concerns first-order physical theories. This idea will resurface in chapters 2-4 in particular.

It is widely accepted to claim that an "ultimate understanding requires a constructive theory" (see Giovanelli 2019 §6). However, there seem to be grounds to doubt this. Why would an ultimate understanding *require* a constructive theory? Presumably, the thought is in order for an explanation to reach the status of a total and final and *complete* explanation, each process at every level must be accounted for. And in order for each process to be accounted for, an ontology must first be specified, from which a world of more complex phenomena is deduced.

One can see the *primitive ontology* programme in the foundations of quantum mechanics as insisting on the need for a constructive theory[12]. There are broadly two routes taken in the current research on the ontology of quantum mechanics. If one commits to a *wave function ontology*, that is, a mathematical object (the wavefunction) represents a real, physical field taken as the ontology of the physical world, one commits to a dimensionality of the world much greater than three (or a four-dimensional spacetime)—contrary to appearances. Instead of representing

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[11] Rayo (2022, p.28).

[12] The "primitive ontology" term can be traced back to Dürr *et al* (1992) and Goldstein (1998), although Mundy (1989) is considered central to the idea. The approach has more recently appeared in different forms by Allori *et al.* (2008), Allori (2013, 2016), Maudlin (2013) and Esfeld *et al.* (2017).

12 particles in three-dimensional space by 12 points in space; each point represented by 3 numbers corresponding to the mutually orthogonal direction of each dimension (*x*, *y*, *z*), a wave function ontologist commits to a single point in 3*N* configuration space, in the case above, a single point in a 36-dimensional space (see Ney & Albert 2013 for detailed discussion).

The primitive ontologist, in contrast, places emphasis on entities living in three-dimensional space (or four-dimensional spacetime). Such entities form the 'building blocks' of the world, providing a clear explanatory account of how properties attributed to macroscopic objects arise. The predominant motivation for the view is that we should keep the scientific image and manifest image closely aligned, that is, we should attempt to connect the scientific image and manifest image with a clear, tractable account. If three dimensions are maintained throughout, this is an attractive feature. The leap from the scientific to the manifest image is far greater for a view which favours a wave function ontology. One has to explain how the world is fundamentally 3*N*-dimensional yet *appears* three-dimensional. *Prima facie,* a theory which endorses a wave function ontology has little contact between the variables in the physical theory and the objects in the world that the theory describes.

Allori (2016) considers the primitive framework to rest on the assumption that mathematics in a physical theory can be sub-divided into representational and non-representational. Objects are organised into those that represent matter, those that specify how those matter-representing objects move in time and others function as tools necessary to connect up parts of the theory. Maudlin (2013) charges that those who endorse a wave function ontology fail to appropriately distinguish between the nature of an entity represented and the structure of its mathematical representation. According to Maudlin, there are no grounds for reading off the nature of an entity from the structure of its mathematical representation. More specifically, there are no grounds for thinking that since the mathematical representation "lives" on a high-dimensional mathematical space, then there must be a high-dimensional real physical space. (For more details on the nature of representation in quantum mechanics, see chapter 4).

Returning to the ontology of an ultimate understanding of reality, I'm not sure that the question which asks what the ontology of our ultimate understanding of reality is, is well posed. Given that ontology is a feature inconsistent amongst our best quantum interpretations of reality (as alluded to above), why is it obvious that the ontology of fundamental reality is such that it can be described by materials of a "relatively simple formal scheme" (in Einstein's words), consistent with a constructive theory? Chen (2021) for example introduces a coherent, non-standard picture in which there is no fundamental material ontology of the universe. One may object that once we have something that avoids foundational problems and successfully predicts the behaviour of matter, a constructive theory is what follows. However, it's not clear that we even have the scientific or philosophical resources to formulate a hypothetical ontology for an ultimate understanding of reality. The best I think we can do is to ask what ontology would exist according to our best and most fundamental theory if that theory were true.

I think this is the extent to which an answer can be formulated. Even if facts can be attributed to the entities that make up reality, it's not clear that these entities are conducive to a constructive theory formulation. A constructive theory might be the aim, but a principle theory might be all we can have.

1.3 Substantivalist or Relationist?

Predating Einstein, Lorentz (1900) also distinguished between types of theories. In Lorentz's (1900) words, the distinction is between "general laws" (p.336) and a "mechanism of appearances" (p.337). Lorentz's preference was for the latter, although this wasn't exclusive (see Frisch 2005). Einstein's (1949, p.53) transformation of Lorentz's pre-relativistic theory of spacetime into special relativity was only achieved via a self-proclaimed breakthrough of re-conceptualising prior constructive ideas as a principle theory, leading to the successful formulation of special relativity. Einstein writes:

> By and by I despaired of the possibility of discovering the true laws by means of constructive efforts based on known facts. The longer and the more desperately I tried, the more I came to the conviction that only the discovery of a universal formal principle could lead us to assured results.

Is a constructive theory of special relativity doomed from the start? The focus of a recent and relevant debate prompted by Janssen (1995, 2002a, 2002b, 2009) and Brown (2003, 2005a, 2005b) assesses the connection between Minkowski spacetime and Lorentz invariance of physical laws. In a nutshell, Brown suggests that Lorentz invariance explains Minkowski spacetime structure (and thus time dilation and length contraction are explained by the structure of matter) whilst Janssen claims Minkowski spacetime structure explains Lorentz invariance (and thus time dilation and length contraction are explained by the geometry of spacetime).

Even more recently, Acuna (2016) suggests that Lorentz invariance and Minkowskian spacetime structure are rather "two sides of a single coin"[13]; the connection between them is not explanatory but rather *analytic*.[14]

Norton (2008, p.825) doubts a constructive formulation of relativity since constructive relativity requires that we recover spacetime geometry from a theory of matter that is "devoid of spatiotemporal presumptions". Such a project can never get off the ground since the theory of matter must presuppose spacetime structure, which is the very structure a constructive theory of relativity seeks to derive. Frisch (2011) suggests that the disagreement between Brown and Janssen is (at least partially) due to it being framed by the principle/constructive distinction and once that framing is removed, there is in fact much more agreement between the two authors. Van Camp (2011) argues that both authors miss an essential feature of the principles of special relativity, namely the constitutive nature of the principles themselves.

The spacetime substantivalist and relationist approaches are salient here. The substantivalist takes spacetime to be a separate, self-standing entity, distinct from the matter contained within it. Relationism, on the other hand, takes spacetime to be a set of relations instantiated in physical objects, thus denying its independent existence. There are many formulations of substantivalism (e.g., *spacetime structuralism*, *manifold substantivalism* or *metric field substantivalism*)[15] and likewise many formulations of relationism distinguished by the spatiotemporal predicates they take to be fundamental (see Huggett 1999). If one assumes either a substantivalist or relationalist position, one still needs to be clear about which features of spacetime they take to be doing the work.

Similar precision is needed in identifying the type of explanation. Janssen's (2009, p. 49) explanatory relation between Minkowski spacetime and Lorentz invariance is an explanation but not a causal one. He writes:

> So in my view Minkowski space-time explains Lorentz invariance. For Brown and Pooley, however, Minkowski space-time is a "glorious non-entity" that can do no explanatory work. I agree that Minkowski space-time is not a substance with causal efficacy, so the sense of explanation I invoke is certainly not causal. I adopted the view, similar to Brown's, that Minkowski space-time encodes the default spatio-temporal behavior of all physical systems in a world in accordance with the laws of special relativity.

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[13] Acuna's (2016) paper is titled, "Minkowski Spacetime and Lorentz invariance: The Cart and the Horse or Two Sides of a Single Coin".

[14] Acuna (2016, p.15) appeals to Kant here: "Kant defined analytic propositions as those in which the predicate concept is contained in the subject concept. In this sense, analytic sentences are explicative rather than explanatory…Lorentz invariance and Minkowski spacetime structure are like the subject and predicate of an analytic proposition."

[15] See Norton *et al* (2023).

Can such a view accommodate a constructive theory of special relativity? A better understanding of what it is to “encode” would certainly help us answer. On the face of it however, if spacetime encodes matter in accordance with special relativistic laws, we are back to square one; we need a constructive theory of these principle-theoretic laws. Brown’s view may provide the necessary apparatus, but according to Norton (2008), more needs to be said when claiming “relativistic phenomena like length contraction and time dilation are in the last analysis the result of structural properties of the quantum theory of matter (2005, p.7-8) and “that Lorentz contraction is the result of a structural property of the forces responsible for the microstructure of matter” (2005, p.132).

Norton (2008, p.826) suggests terms such as “result of”, “because”, and “responsible for” are central to Brown’s thesis but remain ambiguous. One may understand such terms as carrying an *explanatory* weight; one should thus look to the theory of matter for explanations as to why spacetime has the structure it does. One may also understand these terms as carrying an “ontological import” in claims such as: “…the space-time structures [of Newtonian theory and special relativity] … are not real entities in their own right at all” (2005, p.141); “It is more natural in theories such as Newtonian mechanics or SR to consider the 4-connection as a codification of certain key aspects of the behaviour of particles and fields” (2005 p. 142); and “I see the absolute geometrical structures of Minkowski space-time as parasitic on the relativistic properties of the dynamical matter fields” (2005, p.100).

If Minkowski spacetime supervenes on dynamical matter fields and the explanatory role establishes itself in virtue of that fact, then a constructive theory in this vein doesn’t need to concern itself with the ontology of spacetime, it is wrapped up in the constructive theory of matter itself—assuming it’s cogent to construct the geometry of spacetime from a theory of matter (see Norton 2008 for reasons against such an assumption). Of particular significance here is how notions of *fundamentality* relate to the principle/constructive distinction, of which I turn to next.

1.4 Fundamentality in the Principle/ Constructive Distinction

Acuna (2016 p.13) suggests the following principle to characterise the so-called *hierarchical evaluation* between principle and constructive theories:

> P_1) In general, given a realm of phenomena E, for which there is a theory of principle T_p and a corresponding constructive theory T_c, T_c is explanatorily more fundamental than T_p with respect to E.

I take this to be the orthodox view when considering which theory-type is explanatorily more fundamental. A familiar example is the behaviour of an isolated box of gas being explained in the mechanistic terms of its constituent particles (in other words, a statistical-mechanical constructive theory rather than a thermodynamic principle theory).

One reason a constructive theory may be considered more explanatorily fundamental than a principle theory is that the nomological nature of the principle theory is such that we tend not to consider laws to be constituents of a theory in a manner analogous to the particles or fields (for example) of a constructive theory. One may think that laws do not have a status that warrants their inclusion into a theory as *explainers* (as perhaps a Humean about laws might[16]).

If this is the case, that is, if the degree to which a theory is explanatorily fundamental is sensitive to the fundamental constituents of a theory's ontology, then a constructive theory can only be said to more or less explanatorily fundamental if there is a consistent reading of fundamentality as it applies to a theory's ontology. Brown, Pooley, Acuna, Van Camp to name a few employ a broadly reductionist account of physics to inform what they take to be the most effective way to discern the distinction between principle and constructive theories.

The account of fundamentality I take the above authors to endorse (but perhaps not commit to) in their discussion of constructive theories has a number of features. Firstly, the different hierarchically organised levels[17] we appeal to when giving a detailed picture of reality motivates the view that the metaphysical structure of reality is organised in this way too. Secondly, there is an ontological level which can be considered the most fundamental, the ontology of which will be determined by some future theory (chains of ontological dependence terminates at some point). Thirdly, there are mereological relations between levels (e.g., biological systems are composed of elementary chemicals, which are in turn composed of fundamental particles). Moreover, there is a level such that its constituents have no proper parts, they are

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[16] See chapter 3 for details of the Humean account of laws.

[17] For example, facts about biochemistry depend on facts about elementary chemistry, which in turn depend on facts about different branches of physics.

indivisible—we call this the fundamental level.[18] Understanding fundamentality in this way isn't our only option, however. Over the next four sections, I consider some alternatives.

1.5 Infinite Descent

In his *Dreams of a Final Theory*, Weinberg (1992, p.172)—I think rightly—suggests, "we may draw the moral that it is foolhardy to assume that one even knows the terms in which a future final theory will be formulated". Comparably, Schaffer (2003 p.505) considers three reasons to be sceptical of a fundamental level: firstly, there is no evidence for a final theory; secondly, if there is such a theory then there is no evidence that it will postulate a mereological atom (or structural equivalent); and finally, there is no evidence that a final theory's mereological atom—a theoretical entity—has an *ontological* correlate.[19]

An alternative approach to fundamentality is *infinite descent*. Whilst fundamentality is often associated with Newton, infinite descent can be traced back to Leibniz.[20] On this picture, there is (roughly) an *infinitist* hierarchical structure of reality, namely an infinite descent of levels[21] with each level being dependent on that (level) which precedes it—although as I understand the view, it makes no commitment to a particular type of dependence relation. Since Leibniz, the idea has resurfaced in e.g., David Bohm (1957), and is also prevalent in contemporary metaphysics (e.g., Cameron 2008, Dixon 2020, Tahko 2014), and gestured towards (although not made explicit) in the philosophy of physics literature (e.g., Le Bihan 2018, McKenzie 2011; 2012; 2017). The metaphysicians typically focus on whether infinite descent is metaphysically possible; my concern, and the dominant focus within philosophy of physics is the status of fundamentality as a constitutive (or even regulative) principle in physics.

An infinity of levels renders any divide between levels *less interesting*[22] than a hierarchy of finite levels. If the fundamental level is abolished, there is no anchor, no reference and no

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[18] One might also speculate that the hierarchy has a structure in which there are supervenience or nomological relations between levels. One might imagine a structure in which the more derivative layers supervene on those below it, and that one-way nomological features of inter-level relations constrain their behaviour.

[19] I discuss further about bridging the gap between representations (theoretical postulates) and the ontology of the world in later chapters (most notably ch.5).

[20] In a letter to Simon Foucher, Leibniz writes: "…I believe that there is no part of matter which is not - I do not say divisible - but actually divided". (Letter to Foucher, *Journal de Sçavans*, August 3, 1693, GP I 416 [=A II 2, N. 226. Leibniz an Simon Foucher, Wolfenbüttel, Ende Juni 1693, p. 713]).

[21] The nature of these levels we will leave unspecified for now (possible readings might favour levels of description rather than ontological levels, for example).

[22] The notion of interestingness here intends to capture the following: if there are such levels as the *most* primary and *most* derivative, then removing these levels not only relinquishes the privileged metaphysical position of these

ontological division. Whilst there is still a direction of more fundamental and a direction of more derivative between levels, there is no point which separates the primary from the derivative (cf. Schaffer 2003 p. 507). Acuna's principle that a constructive theory is explanatorily more fundamental than a principle theory is, I suggest, more coherent under a view which posits a fundamental level, since one can leverage the explanatory direction from the fundamental base. If on the other hand one endorses *infinite descent*, it's not obvious that there is an analogous distinction between primary and derivative, which problematizes the notion that particular constituents of constructive theories are doing more explanatorily fundamental work.[23]

Let us briefly consider some further non-standard metaphysical views about fundamentality that may weaken the idea that constructive theories do more explanatorily fundamental work.

1.6 Cosmic Void

Chen (2021) suggests a picture in which there is no fundamental material ontology of the universe, instead proposing that derivate (or non-fundamental) facts are completely explained by *nomic facts*, provided the laws of nature are strongly deterministic. As we have seen, the orthodox view is one in which the existence and behaviour of higher-level phenomena is explainable by the existence and behaviour of a fundamental material ontology (plus the physical laws). One might alternatively describe the view in terms of grounding—all facts are grounded in fundamental-level facts. Whilst there are many subtleties involved in the grounding literature (and the relation between grounding and fundamentality), *grounding* can be (informally) presented as the relationship of metaphysical explanation that relates the primary and derivative facts, linking the world across levels. Moreover, grounding is also generally considered to be asymmetric (x grounds y but y does not ground x); transitive, (if x grounds y and y grounds z, then x grounds z); irreflexive (x cannot ground itself); and well-founded (there is a terminus of chains of ontological dependence).

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respective levels but also the levels between them since those levels can be categorised in terms of the most primary and most derivative. This is not to deny that there is still a direction of more fundamental or more derivative between levels for the infinite descent view.

[23] In other words, there is no metaphysical or objective sense in which a level is primary or derivative since there is always infinitely more derivative and always infinitely more primary levels on the infinite descent view, thus problematizing the directionality of inter-level explanations and typical formulations of constructive theories which appeal to, to borrow Einstein's (1919) phrase, "materials of a relatively simple formal scheme".

Chen's unorthodox view suggests that there is nothing material at the fundamental level and instead appeals to the fundamental laws of nature as a candidate for explaining derivative facts. Whilst comparable to the ontological nihilist views of for example, O'Leary-Hawthorne and Cortens (1995) and Turner (2011), Chen's aim is more scientific rather than metaphysical in its method, proposing a particular type of physical theory in order to generate non-fundamental facts from fundamental laws (his view is only coherent for physical theories where strong determinism holds, namely where the laws of nature select a *unique* history of the universe). I suggest that the Cosmic Void picture undermines the claim that constructive theories are more explanatorily fundamental since the view proposes that material ontology (particles, fields) is derivative of more fundamental nomic facts.

1.7 Monism

Which is prior? The single whole, or its many parts? The *pluralist* holds that parts are prior to the whole and so will generally consider (mereological) atoms—understood literally as that which is indivisible—to be fundamental. The *monist* (e.g., Schaffer 2010) on the other hand, views the whole to be prior to its parts and thus considers the cosmos to be fundamental; monism in essence turns the orthodox picture of fundamentality on its head (all facts are grounded in or *obtain in virtue of* the fundamental whole). It's worth noting that for the monist, the relevant ordering is mereological rather than physical size scale[24], thus if the salient levels of fundamentality do not correspond in any useful (or interesting) way to levels of physical size then physical size scale may turn out to be play an insignificant part in our explanations of the world. I return to this point in §1.8.

Schaffer (2010) suggests that there are good reasons from physics to consider entangled systems as irreducible wholes[25], and so given the cosmos forms an entangled system, monism is the preferred metaphysical position. Whilst I do not have space for a full analysis of Schaffer's argument, if it turns out that both physics and metaphysics give us good reasons for thinking that the notion of *the cosmos as a whole* is not a coherent notion then this would *prima facie* weaken attempts to attribute fundamentality to the cosmos.

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[24] Although it may turn out that they correspond.

[25] In §3.4, I give details of quantum entanglement.

Constructive theories are in a peculiar position according to the monist. If the whole is prior to its parts and I attempt to "build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme" as Einstein (1919, p.1) suggests, then it's not clear which set (or sets) of facts a constructive theory must appeal to in providing an explanation. Perhaps one can bite the bullet and admit that the "relatively simple formal scheme" is a scheme associated with the most *derivative* facts to build up a picture of the (more fundamental) cosmos as a whole. Whilst such a view can, I think, be made coherent, it does present a *prima facie* difficulty for those who suggest that constructive theories are more explanatorily fundamental since the direction of explanation for constructive theories typically appeals to more fundamental constituents to explain more derivative facts (e.g., kinetic theory of gases)—contrary to the explanatory direction of monism. On the monist view, the kinetic theory of gases is one that explains more fundamental facts by appealing to more derivative facts, but these derivative facts are not typically attributed with the properties Einstein attributed to constituents of constructive theories.

Considering the nature of constructive theories on the monist picture draws attention to the salient distinction between explanatory fundamentality and what is sometimes called ontic fundamentality; it needn't be the case that the set of facts appealed to in giving an account of our most fundamental explanation must also be the set of facts which are considered to be most fundamental in one's ontology (see for example, Weslake 2010 for related discussion).

1.8 Middleism

We have seen how fundamentality can be attributed to the 'bottom level' or the 'top level' but Sara Bernstein (2021) argues that a coherent and plausible alternative to formulations of fundamentality is one in which a middle level is the most fundamental one, a view she calls *middleism*.[26]

Bernstein (2021, p.1070) focuses on the middle level as determined by size but she claims her arguments "apply, *mutatis mutandis,* to category-based levels" such as biology or biochemistry, (typically considered to sit between categories such as particle physics on the one hand and economics or psychology on the other), and to levels given in mereological terms—

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[26] Bernstein is not a middleist herself; the goal of the paper is rather to position middleism as a viable alternative to the familiar top-level or bottom-level metaphysics of fundamentality.

"above parts but below wholes". According to *middleism*, facts about (for example) particles, atoms, and molecules are determined by middle level facts but so are (for example) planets, stars and galaxies. Bernstein also considers the view in terms of pluralist/monist metaphysics: monist middleism proposes a single entity comprising the middle level in which everything "above and below" is grounded, whilst pluralist middleism maintains the middle level to be occupied by "numerous *fundamentalia*".

In addition to the view that a middle level is the most fundamental one, Bernstein also proposes *Middle Grounding*, the view in which all facts obtain in virtue of middle-level facts. A notable feature of the middleist view, Bernstein suggests, is the *bidirectionality* of ground.[27] We saw in both orthodox fundamentalism (consistent with the views of Brown, Pooley, Acuna, Van Camp) and monism that a single hierarchical 'arrow' can be traced from the most to the least fundamental. Middle fundamentality on the other hand proposes two explanatory 'arrows'; one arrow can be traced from the fundamental to the micro and another arrow can be traced from the fundamental to the macro. If one's best explanation of phenomena hinges on explanations at the fundamental level, the behaviour of galaxies and the behaviour of particles are explainable in terms of medium-sized goods. As touched upon earlier however, it may turn out (as suggested by Holly Andersen[28]) that physical size scale plays an insignificant part in our explanations of the world, and thus the salient levels of fundamentality do not correspond in any useful (or interesting) way to levels of physical size.

The *bidirectionality* of ground suggests that there is a salient distinction between the large (macro) and the small (micro); despite the fact that particles and galaxies are both derivative, the terminology suggests there is a distinction between these two spaces. As a friendly amendment to Bernstein's strategy, the alternative picture is to postulate a single arrow that can be traced from the middle fundamental level to a level which makes no distinction between particles and galaxies. On this view, particles and galaxies occupy the same level of fundamentality but are indistinct in whichever way the bidirectionality presupposes. If physical size scale does turn out to be an irrelevant feature of fundamentality, I see no reason why bidirectionality is an essential feature of the middleist view.[29] Bidirectionality of ground implies that the micro and macro should be kept distinct (in a way left unspecified) despite both operating at the same

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[27] As noted by Bernstein (2021 fn.3), although there is little consensus, her view assumes that grounding can be diachronic. For a dissenting view, see Bennett (2017).

[28] In private correspondence with Bernstein. See Bernstein (2021, p.1078).

[29] Bernstein (2021) is open to the possibility that size need not be relevant for the middleist view, however this amendment is a response to a particular inconsistency in her account if size isn't a salient feature, as she claims.

level of fundamentality, but if size is simply one way to carve up our picture of fundamentality, it seems perfectly reasonable to have unidirectionality from the most fundamental "middle" level to the least fundamental level comprising the most macro and most micro.[30]

I suggest that the distinction between principle and constructive theories, and their associated explanatory depths on the middleist view is opaque for the following reason. The features Einstein attributes to constructive theories, namely that the starting points of constructive theories are "hypothetically constructed"[31] and that such theories "attempt to build up a picture of the more complex phenomena out of the materials of a relatively simple formal scheme from which they start out" are arguably problematized if there is a fundamental middle level. From the way we currently understand middle level science (e.g., bioscience), *prima facie* these are not systems that lend themselves to the description of a "relatively simple formal scheme", and so on such a view one may require a revision of what it is to be a constructive theory.

If one hopes to retain the distinction between principle and constructive theories, and to maintain the proposal that constructive theories are more explanatorily fundamental, I have argued that there are more challenges if the levels of fundamentality and their relations are viewed under more unorthodox metaphysical pictures. Let us briefly return to the principle/constructive distinction in view of these alternative pictures of fundamentality, before discussing the metaphysics of totality in chapter 2.

1.9 Returning to the Principle/Constructive Distinction

This chapter has aimed to illuminate the nature of physical theories and their relation to the world, drawing attention to the particular ways that certain orthodox metaphysical and physical theories carve up the world. Whilst there is a certain clarity in theorising constructively, I hope to have made space for theorising in a way that does not presuppose that constructive theories are more explanatorily fundamental.

It's important to note that if we scrutinize our physical theories carefully enough, there are very few uncontentious examples of theories which can only be given either a principle or a constructive formulation. Many theories employ features relevant to both principle and

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[30] "Middle fundamentality" is then perhaps distracting terminology since it seems to carve up the world according to scale despite rejecting size as a salient feature. If "middle" doesn't refer to size, then what exactly is it in the middle of?

[31] Einstein (1919, p.54).

constructive theories (as suggested above by information-theoretic approaches to quantum mechanics) and as such, there is reason to think that the principle/constructive distinction isn't as substantive as Einstein (perhaps) intended.

This isn't to suggest that the distinction isn't useful. In the above discussion, considering physical theories according to the principle/constructive distinction has been a fruitful way to expose those issues central to the rest of the thesis. I hope to have illuminated particular ways that a physical theory's ontology can be formulated and the motivations for thinking such an ontology should be characterized in a particular way.

One route to understanding the role of a theory's ontology and its explanatory power has been through considering the metaphysics of fundamentality. Different fundamental theories lead to very different (and seemingly plausible) ways to carve up reality; in what follows, I draw on lessons from metaphysics (ch.2) and physics (ch.3) to question whether a theory's ontology is in fact singled out independently of the methods used to represent the world and whether an absolutely general (physical) domain is a coherent notion.

2. Totality

Discussion of totality is often reserved for metaphysics. Authors have typically shown little motivation for an analysis of its place in physics. But even if any philosophical investigation into the function of totality in physics may prove irrelevant to the current practice of physics, a better understanding of its place and potential to affect any extant or future proposal in physics should be welcomed. Thus, the aim of this chapter is to suggest how considerations of totality in logic and metaphysics may be relevant to the broader thesis-aim of understanding the concept of totality in the context of physical theories. This will provide the tools required to explore the notion of totality in physics (chapter 3), the relation between totality and objectivity in quantum theory (chapter 4) and the case study of totality in Everettian quantum mechanics (chapter 5).

2.1 Logic of Totality

The universal quantifier ($\forall$) asserts a domain of totality; its domain is *absolutely* everything. Logically equivalent to universally quantified sentences ($\forall xFx$) are negative existentials ($\neg\exists x\neg Fx$). To say, *all cardinals are red* is to say, *there are no non-red cardinals*.

Atomic propositions are logically independent of each other; it is not the case that if one fact is true, all others are also true (of course). We can say there is no *entailment* between a set of atomic facts and a statement of totality. In other words, in an unrestricted domain, there is no way to transition from a statement about *each* (*there is a red cardinal*) to either a universal quantifier (*all cardinals are red*), a negative existential (*there are no non-red cardinals*) or a totality statement (*there are a total of n cardinals*). In first-order logic there is no logical rule that bridges the collection of atomic facts to a universally quantified sentence. And this is because there is no logical rule that connects a collection of atomic facts to a negative existential, in other words, there is nothing in adding more positive instances to a collection of facts that eliminates the possibility of there being *more* facts (and thus adjusting the total). Whatever the atomic formulae proposed (Fa, $Fb \ldots Fn$), it doesn't follow that $\forall xFx$ is true without adding an extra premise that specifies a, $b \ldots n$ are *all* the things that there are.

Let us begin by acknowledging arguments that exploit the logical paradoxes that result from inquiry concerning absolutely everything there is. Russell's paradox and Dummett's notion of indefinite extensibility are of particular importance but let us begin with Patrick Grim's (1991) suggestion of a proof that there can be no set of all truths.[1]

We are first asked to imagine that there *is* a set of all truths T:

$T = \{t_1, t_2, t_3, \ldots\}$

And then to consider all subsets of T, the power set $P(T)$:

$\varnothing$
$\{t_1\}$
$\{t_2\}$
$\{t_3\}$
…
$\{t_1, t_2\}$
$\{t_1, t_3\}$
…
$\{t_1, t_2, t_3\}$
…

A truth corresponds to each element of the power set. To each set of the power set, a truth can be assigned to whether each element belongs or doesn't belong as a member. Take for example, the element, t_1:

$t_1 \notin \varnothing$
$t_1 \in \{t_1\}$
$t_1 \notin \{t_2\}$
$t_1 \notin \{t_3\}$
…
$t_1 \in \{t_1, t_2\}$
$t_1 \in \{t_1, t_3\}$
…

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[1] For our purposes, one can use "truths" or "facts" interchangeably.

$t_1 \in \{t_1, t_2, t_3\}$

…

The number of truths here is at least as the number of elements in the power set, $P(T)$, but moreover, by applying Cantor's power set theorem, it will always be the case that the power set of any set will *always be larger* than the original set of all truths. To see this, we imagine that there are only as many members of the power set $P(T)$ as there are members of the set T. It then follows that there is a one-to-one function that assigns each member t of T to a set $f(t)$ of $P(T)$. Take any one-to-one function f from T to $P(T)$, and consider the following subset of T:

$T' = \{t: t \notin f(t)\}$

The set T' contains all those elements t of T whose image under the function f does not include t itself. For example, since $T = \{t_1, t_2, t_3, \ldots\}$, we could map:

$t_1 \rightarrow \emptyset$

$t_2 \rightarrow \{t_1, t_3\}$

$t_3 \rightarrow \{t_2\}$

We know that the set T' is a subset of T and so $T' \in P(T)$. But what element t of T can the function f assign to T'? If it's the case that t is a member of T', it's then not a member of $f(t)$ and T' cannot be the set assigned to it as its $f(t)$. Equally, if t is *not* a member of T', it is a member of $f(t)$ and so T' again cannot be the set as its $f(t)$. In either case there is no t which the set T' of $P(T)$ corresponds as $f(t)$ and the initial assumption of $|T| = |P(T)|$ is false. Instead, any one-to-one function f will always leave out an element of $P(T)$, and so $|T| < |P(T)|$.

Since each element of $P(T)$ has a corresponding truth, Grim concludes, there will always be more truths than there are members of T, and so any set of truths T can never account for *all* truths; there is no set of all truths. "Truths" in Grim's framework are not in any sense merely linguistic entities, we can replace them with e.g., "states of affairs" or "facts". The conclusion is the same: there can be no set of all states of affairs; no set of all facts.

2.2 Indefinite Extensibility/Russell's Paradox

Russell's (1903) paradox arises from considering *all* sets within naïve set theory. Some of these sets are members of themselves whilst other sets are not members of themselves. As such, one can consider the set of all sets that are not members of themselves. It appears that such a set is a member of itself iff it is not a member of itself.

Naïve set theory endorses the naïve or unrestricted Comprehension Axiom, which assumes (roughly) that one can determine a set from precisely specifying a particular property. If, for example, P is the property of being a prime number, then the set of prime numbers, S, can be defined as $S = \{x\text{: } \mathrm{T}(x)\}$. In other words, for every formula, there will exist a set whose members consist of all and only those objects which satisfy that formula. Russell's paradox follows from the assumption of this axiom: if $\phi(x)$ stands for $x \in x$, and we consider the Russell set, R, to be $\{x\text{: } {\sim}\, \phi(x)\}$ then, paradoxically, R is the set whose members are precisely those objects that are not members of themselves. If R is a member of itself, then it must satisfy the condition that it is not a member of itself, and thus R is not a member of itself. If R is not a member of itself, then it must not satisfy the condition that it is not a member of itself, and thus must be a member of itself.

A common response to the problem is to reject the set of all sets that are not members of themselves. One can, via the so-called Separation Axiom, limit the way one determines a set from the specification of a particular property. The axiom states that for any consistent set, S, and any formula, $\phi(x)$, containing x as a free variable, there will exist a set $\{x \in S : \phi(x)\}$ which contains members of S that satisfy $\phi(x)$. Thus in substituting $\phi(x)$ for $x \notin x$, we reach: $\{x \in S : x \notin x\}$, which isn't contradictory since the set contains only those members *found in S* that are not members of themselves. By omitting itself from the set, there is no contradiction.

Russell (1907, p.36) characterized the paradox in terms of *self-reproductivity*: it results "from the fact that…there are what we might call *self-reproductive* processes or classes. That is, there are some properties such that, given any class of terms all having such a property, we can always define a new term also having the property in question." Thus in attempting to define a collection of terms, the collection itself generates a new term which has that property.

Building on Russell's analysis, Dummett (1963, pp.195-196) proposes the idea of *indefinite extensibility*: "a concept is indefinitely extensible if, for any definite characterization of it, there is a natural extension of this characterization, which yields a more inclusive concept." Extended characterizations, he continues, will typically "be formulated by reference to the previous, unextended, characterization." It's perhaps of interest to note that Russell's notion of self-reproductivity refers to *processes* or *classes*, whilst indefinite extensibility, according to

Dummett, is a property of concepts. The distinction is of little importance for our purposes however; both result from consideration of totalities, which is the central concern here.

An example of an indefinitely extensible concept, and one frequently discussed by Dummett, is the concept of an ordinal number[2]. For any collection of ordinals, there is always a larger one. In keeping with the way Cantor characterized the ordinals, then for any ordinal α, there is always a next number $\alpha + 1$ which succeeds α. If one considers the set of all ordinals, then such a set must also be an ordinal. If this set is an ordinal, it must be a member of itself.[3] It is impossible to give a definite extension to the concept and thus is characterized as indefinitely extensible. This is reiterated in Dummett (1993, p.441): an indefinitely extensible concept is "one such that, if we can form a definite conception of a totality all of whose members fall under the concept, we can, by reference to that totality, characterise a larger totality all of whose members fall under it."

Recall that an absolute general inquiry is an inquiry concerning absolutely everything there is. In order for a domain to consist of absolutely everything, such a domain will require a definite extension. But the lessons of indefinite extensibility would suggest that a domain consisting of absolutely everything must be indefinitely extensible, and so there is at least some motivation for thinking that there isn't an all-inclusive domain.

Perhaps this is too hasty. Even if we take seriously the idea of indefinite extensibility, it's not obvious that one is subsequently in a position to make metaphysical claims about an all-inclusive domain. Those who consider the world to consist of objects that exist independently of anyone's thoughts or linguistic practice are perhaps in a better position to draw metaphysical conclusions from considerations of indefinite extensibility—and, more importantly, that it is precisely this world of objects that considerations of indefinite extensibility concern. If there is a particular correspondence between the objects to which the indefinitely extensible concepts refer and the constituent objects of this world, this would certainly provide a more compelling reason to make more metaphysical claims.

But such issues are not settled by consideration of absolute generality by itself. Hence Glanzberg (2004, §IV) is far more modest about the types of conclusions one can draw from indefinite extensibility, suggesting a more linguistic rather than metaphysical reading. The reason there is no absolutely unrestricted quantification, he argues, is because one cannot *specify*

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[2] The concept of 'set' is typically considered to be indefinitely extensible too; the concept of 'self-identical' is a more controversial suggestion (see Rayo and Uzquiano's 2006 introduction).

[3] This is the lesson of the Burali-Fori paradox.

absolutely unrestricted domains. Such a result doesn't imply any limit on what the world is like however, and it doesn't bear on whether the world is determinate in the relevant metaphysical sense.

This is, in a nutshell, my most pressing concern. How do the logical difficulties we encounter in establishing an all-inclusive domain bear on the notion that the physical world itself is an all-inclusive domain? In other words, are the lessons we learn from the paradoxes of set theory orthogonal to considerations of the physical world, or do they provide an insight into what the physical world is actually like? Are these logical paradoxes direct evidence for the anti-absolutist position? And if not, what *do* they teach us about the world? These are questions which are central to the remainder of this chapter and those that follow.

2.3 Metaphysics of Totality—(Anti-)Absolutism

My predominant concern in the rest of this chapter is to setup the debate between absolutism and anti-absolutism, which I take to be central to the metaphysics of totality. I will subsequently endorse Rayo's (2019, 2022) view in outlining my position within the debate and then utilise this view in the discussion of quantum theory in chapters 4-7.

As I will understand it here, absolute general inquiry is inquiry concerning absolutely everything there is. Rayo and Uzquiano (2006 p.2) propose two related but distinct questions that probe the issue:

> *The Metaphysical Question*
> Is there an all-inclusive domain of discourse?
>
> *The Availability Question*
> Could an all-inclusive domain be available to us as a domain of inquiry?

There are those (e.g., Lewis 1991, p.68) who have suggested that in voicing scepticism about the metaphysical question, one undermines the sceptic's position: in asserting that one cannot quantify over absolutely everything, one implies that there is in fact an all-inclusive domain that one cannot quantify over. Proposing either the positive argument in favour of absolute general inquiry or the negative argument that rejects absolute general inquiry seems to require an assumption in favour of the absolutist in order to state the position. Scrutiny of this line of thought is an interesting project in itself, but since it is concerned with much broader philosophical issues, it is not something I intend to address in detail here.

Stating the thesis of anti-absolutism needs a little precision. As suggested, authors have voiced concern that the sceptic's position is undermined when formulating the metaphysical question ('Is there an all-inclusive domain?'): in asserting that one cannot quantify over absolutely everything, one implies that there is in fact an all-inclusive domain that one cannot quantify over. I therefore follow Rayo (2022) and suggest that the anti-absolutist position is not one that says there isn't or couldn't be a quantifier that ranges over absolutely everything but rather that "*there is no sense to*" the absolutist's discussion of absolute generality.[4]

The thesis of absolutism has largely been questioned by appealing to set-theoretic paradoxes of the type discussed above (e.g., Dummett 1963; Parsons 1974; Glanzberg 2004) but Rayo, whilst acknowledging the significance of the set-theoretic results, instead challenges the thesis of absolutism by considering the relation between language and the world it represents, a view he terms *Recarving Anti-Absolutism*.[5] Let us first begin with an analogy borrowed from Rayo (2022), intended to illuminate the role of ontology when there is no sense to be made of an absolutely general domain. The analogy is *units of measurement* and proceeds as follows.

Whilst it an objective fact that, for example, the height of the chair I am sitting on is 1 metre (±1%), there is little motivation to interpret the unit of measurement used to describe this objective fact, namely *metres*, as metaphysically privileged. The unit of measurement here is, in Rayo's words (2022, p.5) a "parochial tool" used to describe an objective fact. I can choose an equally parochial but different tool, say feet, to describe the same objective fact: the height of the chair I am sat upon is 3.28 feet (±1%). Similarly, there is no metaphysically preferred ontology for describing the world. Rayo puts the point metaphorically: "when God made the world she decided *how* the world would be, but she left it to us to describe her creation using whichever "ontological units" we found most useful."

More precisely, Rayo endorses the following two claims:

> The first is a form of realism: the claim that there is a definite fact of the matter about how the world is. The second is a substantive assumption about the relationship between our language and the world: that a single way for the world to be can be fully and accurately described using sentences with very different logical forms. For example, the objective feature of the world that is fully and accurately described by saying "Socrates died" might also be fully and accurately described by saying "Socrates's death took place" (or "dying occurred Socratishly").

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[4] As suggested in the introduction, I understand "there is no sense to…" to mean that "there is no coherence to…".

[5] Whilst such a view has appeared in various forms of analytic philosophy (see footnote 6 of Rayo 2019), Rayo claims that it has largely been ignored by absolutists.

To unpack the first claim, Rayo proposes "a space of worlds $\mathcal{W}$" and assumes "that exactly one world in $\mathcal{W}$ is actualized". Moreover, Rayo presupposes "that each world in $\mathcal{W}$ is a way for the world to be but we won't presuppose every way for the world to be is metaphysically possible."[6] Such presuppositions enable the following (first) claim to be put in the following terms:

> Realism: There is a definite fact of the matter about which world in $\mathcal{W}$ is actualized.

Recall the second claim is the following: "that a single way for the world to be can be fully and accurately described using sentences with very different logical forms." Rayo continues:

> A proposition, as I will understand it here, is just a way for the world to be. A fact, as I will understand it here, is just a true proposition. (In other words: a fact is a way for the world to be such that the world is, in fact, like that.) We will model a proposition as a subset of $\mathcal{W}$ and let a proposition count as true just in case it contains the actualized world in $\mathcal{W}$...To keep things simple, I shall focus on a first-order language L. Say that an interpretation $[\![\ldots]\!]$ of L is a function that assigns a proposition $[\![\phi]\!]$ to every sentence ϕ of L that one wishes to have available to use.

From such presuppositions, the second claim is put in the following terms:

> Legitimacy: All it takes for $[\![\ldots]\!]$ to count as a *legitimate* interpretation of L—all it takes for it to constitute a fully adequate and maximally robust connection between our language and the world it represents—is for it to respect logical entailments.[7]

Rayo's (2022, p.7) example will be helpful here: suppose I think there to be no difference between "Socrates's dying" and "Socrates's death taking place". As such, either the locution "Socrates died" or the locution "Socrates's death took place" can be used to accurately describe a single, objective feature of the world; the set of worlds w (a subset of $\mathcal{W}$) in which Socrates died is just the set of worlds in which the death of Socrates took place. In contrast, the absolute first-orderist would disagree. Since the two descriptions have different logical forms, it cannot be the case that either can be used to accurately describe a *single*, objective feature of the world—descriptions with different logical forms cannot correspond to the same fact.

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[6] Worlds are assumed to be pairwise incompatible and jointly exhaustive but not maximally specific.

[7] An interpretation $[\![\ldots]\!]$ respects entailments iff whenever $\Phi \vDash \Psi$, then for any world w, the following condition is met: if for every $\phi \in \Phi$, $w \in [\![\phi]\!]$, then for some $\psi \in \Phi$, $w \in [\![\Psi]\!]$. See Rayo (2022), footnote 10.

This is precisely the notion that the *unit of measurement* analogy is intended to illuminate. Any unit of measurement can be adopted to describe the height of my chair—it is a way of relating my chair to the dimensions of other objects—however, the feature of the world that the chosen unit of measurement describes does not change. Each unit of measurement provides a “framework”, to use Rayo’s (2022, p.8) term, for relating certain salient features of the world to other salient features. The same structural relations apply to the Socrates’s case; one is simply afforded different “ontological units”[8].

In the description, “Socrates died”, the ontological units according to Rayo are: 1) “The property of dying”, and 2) “Socrates”. On the other hand, in the description ‘Socrates’s death took place’, the ontological units are: 1) “Socrates’s death” and 2) “The property of taking place”.

Crucially for Rayo (Ibid., p.8), an “ontological framework for conceptualizing propositions” follows from the fact that an interpretation ⟦. . .⟧ “respects logical entailments” (see the second claim, *Legitimacy*, above): objects are assigned to singular terms, whilst properties are assigned to atomic predicates. Whilst there are many ways to describe a fact using a compositional language, Rayo (Ibid.) argues, being able to carve up the world into objects and properties is of central importance to the anti-absolutist: “the anti-absolutist thinks that language will only deliver an ontology — it will only characterize the world on the basis of “ontological units” if it is able to deliver an articulation of the world into objects and properties.”

The nature of these objects and properties requires some explanation. Rayo cites Frege (1892, 1894) whose famous metaphor of “carving” is, he suggests, in some ways appropriate in the present context but unhelpful in others. The idea is that a compositional language “carves up” propositions into objects and properties. The concern here is that Frege’s metaphorical terminology fails to acknowledge a particularly salient feature of the anti-absolutist’s position. The metaphor of “carving” seems to question the status of objects and properties as entities independent of our language; it suggests that the existence of objects and properties is only brought about by our linguistic resources. The anti-absolutist however takes it to be the case that there *really are*[9] objects and properties and that their existence is language and mind independent. Objects would still be objects even if there were no minds or languages to carve entities into objects and properties.

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[8] Rayo’s (2022) term.

[9] There’s of course a lot more one can say about the nature of existence, but given the aim here is to distinguish the anti-absolutist position from a view which takes it to be the case that objects and properties are brought into existence by our use of language, I defer more detail to another occasion.

Moreover, Rayo (2022, p.11) introduces the notion of an *aspect*, which is used to define what it is for something to be an object or property. An object (or property) is "thought of as an *aspect* of a way for the world to be". Rayo also introduces the notion of *salience*: aspects of a particular fact are "*rendered salient*" by linguistic descriptions. The following example is given:

> Venus is an aspect of the fact that Venus is a planet that is rendered salient by "Venus", in virtue of rendering salient commonalities between the ways for the world to be that are paired with "Venus is a planet", Venus is unwelcoming", and so forth. The property of being is an aspect of the fact that Venus is a planet that is rendered salient by "is a planet", in virtue of rendering salient commonalities between the ways for the world to be that are paired with "Mars is a planet", "Jupiter is a planet", and so forth.

Rayo (Ibid.)

Here then lies the distinction between the Fregean relation between objects, properties and language and Rayo's proposal: objects and properties are not *created* by language; rather, certain *aspects* of a particular fact (recall an object or property is "thought of as an *aspect* of a way for the world to be") are "*rendered salient"* by language. The way that particular aspects stand in relation to the ways the world can be is not something that generally depends on either minds or language. Crucially, however, the *salience* of an "aspect of a way for the world to be" is dependent upon the *representational* resources used to describe the world. Rayo (Ibid.) concludes:

> If we don't decide what aspects of the world to focus on, metaphysics won't help. Venus is there to begin with, but whether or not it is included in the domain of discourse of an astronomical language will depend on the syntactic categories of the language, and on the connections between ways for the world to be that are rendered salient the expressions in those categories.

For those readers still left wondering what motivates such a view, the reasoning is most perspicuous when contrasted with an alternative view, which Rayo (2019, p.6) terms "*The Metaphysical Conception of Language*." Such a view *does* presuppose a "metaphysically privileged articulation of the world into constituents." There *is* a particular description of the world which is considered (the most) metaphysically salient. The notable point for our purposes here is that for Rayo (2019 p.10), this so called "*language-transcendent domain*" is incoherent; there is no particular description "that is significant from a purely metaphysical point of view and therefore significant independently of how the world happens to be represented."

We are now in position to consider absolutely general quantification on the anti-absolutist view. Recall that an object or property is a particular fact of which its relevance is dependent upon our *representational* resources. Consistent with the previous discussion of Russell's paradox and Dummett's indefinite extensibility concept, the anti-absolutist considers these objects or properties to be of a similar, open-ended, form: give the anti-absolutist a collection of facts and she can use that collection to characterize more. She can characterize the Russell set R, the set whose members are precisely those objects (or properties) that are not members of themselves, a set that must be distinct from the collection of objects initially proposed. For those who endorse an absolutely general domain, R may be rejected on pain of contradiction—the absolutely general domain is not setup to accommodate objects such as R. The anti-absolutist on the other hand, denies that the world must be metaphysically setup in this way; rather, to expand and accommodate an object such as R, one need only set up the right language to articulate R's place in the domain.

Objects on the anti-absolutist picture are therefore *open-ended*. This of course raises deep concerns for ontological questions: in Rayo's (Ibid., p.14) words, "Either the items in the domain exist or they don't!". This response is only valid if an ontology is singled out independently of the methods used to represent the world. And it is precisely this assumption that the anti-absolutist wishes to deny; distinguishing one way the world can be be from another is inextricably linked to how the world is represented. Thus if a domain of objects is established by a particular description, one can use this description to characterize a further description of the world and thereby expanding one's original domain of objects.

"Aspects", to use Rayo's (2022) term, exist independently of our representational resources, but it is precisely those representational resources that are required to single such aspects out. One cannot simply construct objects into existence by introducing a particular object into a given language and interpreting it accordingly. An object's *theoretical* role must be satisfied; arbitrary objects stipulated into existence have no place within the anti-absolutist picture. As Rayo (2022, p.14) puts the point, "an aspect of a feature of the world is no less objective than the feature itself: it is there to begin with and would have been there independently of our representational efforts."

There is nothing significant — metaphysically — about those particular descriptions of the world picked out by our representational methods. Whilst it may be true that there are electrons or hydrogen atoms, the particular descriptions we use to identify the relevant feature of the world have no metaphysical significance. There is no single, privileged description we attribute to those features of the world. The facts we attribute those descriptions to, can be described using many different, entirely separate sets of distinctions.

Rayo (2022, p.28) puts the point thus:

> …although she [the anti-absolutist] thinks it is true—strictly and literally—that there are oxygen atoms, she also thinks that there is nothing metaphysically significant about that particular description of the relevant feature of the world. The very facts that we currently describe using oxygen-talk might have been described using a separate set of distinctions. So there is nothing about the way the world is, independently of our representational capacities, that makes the distinction between there being oxygen and not "objectively correct". It is *because* the distinction is so useful that it is advisable to describe the world as containing oxygen atoms.

Whilst this type of view may be a radical departure from much of mainstream metaphysics, it has been considered and defended in various forms over the past century or so.[10] And whilst there may be a great deal of metaphysics to give up in adopting the view, there is a lot to gain from rejecting the idea that there is such a thing as a particular ontology which is entirely distinct from our (representational) descriptions of the world; an *objective* set of facts to which our descriptions purport to get ever closer to. This departure from contemporary metaphysics will become particularly unsettling when it is applied to discussions of totality and physics—after all, *prima facie*, physics seems particularly inhospitable for an anti-absolutist view of the form above.[11]

Let me finish this chapter by raising a fleeting (and speculative) remark by Rayo (2022, p.3), who suggests, "If the "absolutely general" domain were taken to consist entirely of physical objects, a good answer might not be so hard to find, since it might be grounded in, e.g. the number of particles created in the Big Bang." I take this point to indicate the central difference between Rayo's view and the thesis presented here, namely, *physical anti-absolutism*: I propose that "if the absolutely general domain were taken to consist entirely of physical objects", a good answer *would still be* hard to find. In the following chapter, I turn my attention to physics to motivate *physical anti-absolutism*, the view that there is no sense to the notion of an absolutely general *physical* domain.

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[10] An argument often discussed by Rudolf Carnap (see Putnam 1987) but has resurfaced in the work of Eli Hirsch (1993) and also Hilary Putnam (1987), might be of interest here. Whilst a world containing x_1, x_2 and x_3 may be said to only contain three individuals, there are grounds to argue (through a particular mereological reading) that the world in fact contains seven individuals: x_1, x_2, x_3, x_1+x_2, x_1+x_3, x_2+x_3 and $x_1+x_2+x_3$. Putnam suggests that the identification of individuals is relative to a particular "conceptual scheme" (Putnam 1987, p.32), and there is no description of individuals independent of such a "conceptual scheme". If there is no fact that can be established independent of a particular scheme, then there simply is no fact about what there is. There is little motivation to suggest either three or seven is the correct answer.

[11] The intuition here is for two reasons. Firstly, the orthodox view in physics is the *closed systems view*, which considers closed systems to be fundamental (see §3.8). Moreover, standard models of cosmology typically describe the universe as closed. Secondly, we take physics to be the study of all physical systems—if there is no sense to the idea of 'all physical systems', there is at least some tension in its proposed aim.

3. Physics of Totality

My broad motivation in this chapter is to suggest how physics can illuminate metaphysical discussions of totality, and equivalently, to illuminate and subsequently challenge a substantial metaphysical assumption inherent in our understanding of physical theories. By considering the intersection of metaphysics and physics, we will improve upon extant accounts and obtain a better total theory as a result. In what follows, I explore the relevance of the logic of totality and the metaphysics of totality in the context of physics.

In light of the logical and metaphysical difficulties in establishing that there is an all-inclusive domain, the question for physics is whether these logical and metaphysical necessities have a physical analogue. The suggestion here is that there is: it is a *nomological* necessity that one can always add more to a particular ontology, and as such there is no sense to the idea of an all-inclusive *physical* domain. To see this, I'll introduce an argument of Ismael's (2019) and subsequently explore its application in both classical and quantum settings.

Ismael's argument concerns the "Paradox of Predictability", introduced into the philosophical literature by Michael Scriven (1965) in his paper, "An Essential Unpredictability in Human Behaviour", arguing that it is possible to create systems which are deterministic but cannot—even in principle—be predicted. Scriven presents his argument as an argument about the unpredictability of human behaviour, but as we will see, the argument is not *specific* to human behaviour. Central to Scriven's paradox is the combination of firstly, the fact that in a deterministic universe everything is predictable, and secondly that in such a universe it is possible to create a system such that revealing a prediction of its behaviour will prompt an alternative behavioural response. Roughly, the idea is that one can create deterministic systems that either have access to the information about its predicted behaviour or have its predicted behaviour revealed to it, and then behaves in a way that runs contrary to the prediction. It is revealed to me that I am predicted to take the left path, so I take the right path. Whilst Scriven's paper prompted a number of responses at the time (Lewis and Richardson 1966, Goldman 1968, Good 1971, Mackay 1971; 1975, Boyd 1972, Roberts 1975), few conclusions were ever reached. In the last few years however, the paradox has been revived once again (e.g., Holton 2013, Ismael 2016; 2019, Rummens and Cuypers 2010, Rummens (forthcoming), Dorst 2022, Gijsbers 2023).

The Paradox

Let us assume a deterministic universe, by which I mean the initial state of the universe and the physical laws taken together determine all physical events. Thus everything that will happen can—in principle—be predicted.[1] Let us then suppose that there is a *predictor*, a system that takes the initial state of the universe and the physical laws as its input and subsequently computes everything that will happen. Consistent with determinism however is another system, call this a *counterpredictive device*, which always does the opposite of what the *predictor* has predicted. The *predictor* thus cannot predict what the *counterpredictive device* will do—hence the paradox.[2]

Discussion concerning the approach to (and how to define) determinism in this context is often limited but we can follow Ismael (2016, ch.7) who succinctly writes, "a universe U is deterministic when, for any arbitrarily chosen time t_0, there exists a law which maps the initial state of the universe U_0 at time t_0 in a unique manner onto the state of the universe U_t at any arbitrarily chosen later time." Accordingly, a predictor is then a subsystem, S, of the universe, U, that can predict all future events.[3] And a counterpredictive device is a system which takes information about its future as input and produces an act to the contrary as its output. In Ismael's words, the device, "computes a function from predictions about what it will do to actions such that if it is predicted that it will P, it does the opposite (~P)." Any embedded system that can calculate a function (with x as its input and y as its output) is sufficient: a simple machine or computer can be programmed such that when inputted its prediction of moving a pointer to the left, it moves a pointer to the right.

Even so, one might suggest that there is an even more pressing objection, namely that the paradox depends on the counterpredictive device receiving an input of its predicted behaviour. If I am not informed that I will take the left path for example, there is no guarantee that I will take the right path. There is however no reason why a subsystem of a deterministic universe—that can predict all future events in that universe—is challenged by the fact that some predictions may not be disclosed. As Scriven (1965, p.414) suggests, "in the present case, *one cannot make true predictions at all.* Secret predictions are still predictions; unmakeable ones are not."

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[1] There are difficulties here, such as the effects of the measurement process on a system and the relevance of information outside one's causally connected past, both of which will be discussed in the rest of the chapter. Prior to Scriven's paper, Popper (1950) notably explores some relevant limits of predictability in a deterministic universe.

[2] Ismael (2016, ch.7) points out that the paradox "is not a paradox in the logical sense…it doesn't produce contradiction", subsequently adopting the term, "puzzle" instead. For historical consistency, I'll adopt the more widely used term, "paradox".

[3] The salience of whether the prediction is made from a system embedded within the universe or external to it is addressed in Rummens and Cuypers (2010) and is discussed in the following section.

Whilst typical formulations of the paradox of predictability include the prediction being revealed to the counterpredictive device, it's not clear that this is an essential feature of the paradox. Let us presume that the predictor draws a particular dataset and runs a specific code to generate its prediction. One can then build a counterpredictive device that also uses that particular dataset and that specific code to generate the same prediction—it then computes a function from this prediction, to paraphrase Ismael, such that any prediction P will generate the opposite response (~P). Whilst this effectively diminishes the need for the prediction to be revealed to the counterpredictive device, Lewis and Richardson (1966) suggest that if the counterpredictive device has the capacity to generate and then counter the prediction then the predictor can subsequently counter the counter prediction. This has led some authors (Roberts 1975; Good 1971; Lewis and Richardson 1966) to introduce ideas about computational speed to the discussion of the paradox, namely the respective rate at which the predictor and counterpredictive device can compute each other's actions.

Rummens and Cuypens (2010, pp. 238-239) consider a number of ways to reject Lewis and Richardson's (1966) proposal, including the suggestion that (on the assumption that both the predictor and counterpredictive device are able to compute with infinite speed) "the to-and-fro scenario… simply captures the typically oscillating nature of the paradoxical equation *P = not-P*", and so the paradox remains.[4] Gijsbers (2023, p.583) argues that there is no reason why we can't "remove the predictor as an independent entity and *identify* it with the predicting part of the counter." (Original emphasis). The paradox remains intact, he argues, if the counterpredictive device falsifies its own prediction.

Whilst there is an intuition that the paradox of predictability is dependent upon the disclosure of the prediction, I conclude that this isn't a serious worry. In the following section, I'll consider some responses to the paradox.

Paradox of Predictability: Some Possible Readings

One might suggest that it simply isn't possible to build an effective counterpredictive device in a deterministic universe, but as I suggested earlier, a counterpredictive device can be programmed from any subsystem of a universe U that can calculate a function (with *x* as its input

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[4] As noted by the authors, see Wormell (1958).

and *y* as its output). This is clearly consistent with a deterministic universe (e.g., a Newtonian universe) and so is not an effective strategy; I therefore set it aside.

The second strategy is to reject the thought that every event is predictable in a deterministic universe. Rummens and Cuypers (2010, p.234) discuss this view by proposing two salient kinds of predictability: external and embedded.

External (or Laplacean[5]) predictability, according to the authors, is "the possibility of a (God-like) external observer, not part of the universe *U*, to make predictions of all the future events in *U* on the basis of its perfect knowledge of the initial conditions U_0 and the law-like function f_L."

Embedded predictability on the other hand, "holds in a universe, *U*, if there exists a subsystem, *S*, embedded in *U*—for instance, a highly intelligent (human) being or a very powerful computer—that is able to predict all the future events in *U*."

The authors suggest that one can resolve the paradox by understanding that determinism entails *external predictability*; counterpredictive device scenarios however suggest that determinism does *not* entail *embedded* predictability.[6]

Rummens and Cuypers are careful to distinguish their view from those authors (e.g., Suppes 1985 and Bishop 2003) who suggest that there are epistemic constraints for a subsystem predicting future events in a deterministic universe. An embedded finite subsystem may be unable to carry out the required measurement for obtaining facts about the initial conditions of the universe or may experience representational limitations in capturing the initial value of a particular variable (if the value is irrational, for example). Rummens and Cuypers (2010, p.235) however insist, "that *embedded predictability* cannot obtain in a deterministic universe even on the idealizing assumption that the epistemic limitations at issue are removed."

On their view, if P is the embedded predictor's prediction and A is the counterpredictive device's action, then P is a description of how the prediction, a physical event in time, is uniquely determined by the initial state of the universe plus the physical laws; A is also a description of how the action—again, a physical event in time—is uniquely determined by the initial state of the universe plus the physical laws. Moreover, the prediction has to satisfy the

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[5] Laplace (1814) famously imagined an intelligence that knew the position and momentum of every particle of which the universe is composed (plus all physical laws), proposing that in a deterministic universe, such an intelligence could successfully predict everything that happens over the course of its history. Laplace's intention was to draw attention to consequences of the principles of determinism, shedding light on the idea that the initial conditions plus the physical laws are sufficient to fix the universe's entire future.

[6] See also Popper (1950) and Mackay (1960, 1961, 1967, 1971, 1973) for previous attempts to make a case against embedded predictability.

equation P = A. Crucially however, this equation has a *physical* interpretation and as such the prediction can only be successful if it correctly picks out the future action A, but there is no guarantee that P = A since the values of P and A are already determined.

In contrast, *external predictability* entails, using the authors' notation, prediction P*, which does not have a physical interpretation and is thus not determined by the initial state of the universe and is therefore not subject to this problem. In other words, the equation P* = A can always be satisfied since P* is not physical, that is, P* is not contained within "the law-like causal chain of events in the deterministic universe" (Rummens and Cuypers 2010, p.233).[7]

Ismael (2016, 2019) also develops an account to reject the thought that every event is predictable in a deterministic universe. Ismael (2016, p.175) points out that the initial conditions of the universe entail facts that determine the choice of the counterpredictive device, but one can read this statement in two ways:

1. (Initial conditions) *nomologically entail* the output of a counterpredictive process.
2. (Laws + initial conditions) *logically entail* the output of a counterpredictive process.

Given there is reason to think that nomological entailment is just *lawful* entailment, these two readings may seem interchangeable, but Ismael argues that "re-writing 1 as 2 encourages a subtle mistake". The second reading encourages one to think that the laws and initial conditions are "already in place" (Ismael 2016, p.176) beforehand—at the initial moments of the universe. In contrast, the first reading, Ismael argues, does not encourage one to think that the physical laws and the initial conditions are both in place before the counterpredictive process—and it is this which forms the resolution of the paradox. If the laws are in place beforehand, then our actions (and the actions of a counterpredictive device) will be a foregone conclusion, consistent with the initial conditions plus the physical laws. If they aren't in place beforehand, then this argument fails.

How should one think about the physical laws if we aren't to think of them as being in place beforehand? One distinction relevant for a response to this question is between a *governing conception of laws* and a *supervenience* account of laws. According to the *governing conception of laws*, laws of nature, "*do* something—they govern what goes on in the universe" (Beebee 2000, p.580),

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[7] Gijsbers (2023) argues that it isn't clear how an external predictor can make a prediction that an embedded predictor can't make. Given an external predictor adopts a particular process (that may for example take as its input the initial state of the universe plus physical laws) then in principle it's possible for an embedded predictor to adopt the same process (in whichever form that process happens to take).

they are entities "that *produce* or *govern* and thereby *explain* the evolution of events" (Loewer 2012, p.118).

On the supervenience account of laws, the world is just local matters of particular fact. Often called *Humeanism*, global laws are distributed patterns in this manifold of fact, they are *generalizations* (sometimes *reports* or *summaries*) whose truth depends on this distribution. On this view, if one attempts to say what these laws are, one must implicitly incorporate, in Ismael's (2019, p.486) words "information from the future." A *supervenience* account of laws (the most familiar route being the view of David Lewis—see e.g., Lewis 1986) however, proposes that laws are not there in advance, and do not govern or guide history; they are things "that come into view as history unfolds" (Ismael 2016, p.177).[8]

An insight from Lewis's view, Ismael (2016, p.177) suggests, gives us a general solution to the paradox of predictability. The insight is a distinction between "higher-order facts" which are derivative of the "*ontologically ground level facts*." On the one hand, ground level facts are facts concerning the (spatiotemporal) arrangement of events in a manifold. On the other hand, the arrangement of events in the manifold form *patterns* and it these patterns which higher-order facts are concerned with. Ismael's use of phrases such as "in place beforehand" are meant to shift "attention to the on-the-ground immanent connections between one spatiotemporally localized event and another." On the (Lewisian) supervenience account of laws, laws belong to the higher-order facts; laws are not part of the ontologically ground level facts and do not belong to the immanent connections between particular spatiotemporally localized events. They do not *govern* or *guide* events in history.

To be more precise about what is included in the ontologically ground level facts, Ismael (2016) makes a distinction between the "*global laws of temporal evolution*" ("GLOEs"), that link the state of the universe as a whole at one time to its state at any other time, from the *local laws* that link the state of matter in one spacetime region to the state of the matter in the spacetime region that immediately surrounds it. Ismael (2016, p.178) suggests that in a classical universe, the ontological ground level facts include events (and their spatiotemporal arrangement into a manifold) and the local laws, but crucially *not* the GLOEs. The GLOEs are rather patterns of *higher-order facts*, "spread across the whole manifold, lying partly in the past and partly in the future. Unlike the local laws, they emerge as history unfolds." So when one programs a

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[8] A supervenience account of laws is sometimes called *Humeanism* (since this is the label Lewis gave the view) or *Lewisian Humeanism*. I have omitted many details of the view here since most aren't essential for the intended purpose of illuminating the paradox of predictability. For those wanting more however, see Weatherson 2021.

counterpredictive device, the device isn't pre-programmed with information that will specify its behaviour at every future time, rather one prescribes local connections that enable the device to "*post*program its behaviour as a response to input."

Ismael's concern here is determinism (and the purported threat it poses to practical, on-the-ground freedom) but a crucial corollary of her argument concerns totality. In a rather downplayed footnote, Ismael (2016, p.178 fn.7) suggests that GLOEs are only deterministic if one explicitly adds a postulate that stipulates that there are no exogenous influences, a postulate that effectively *closes* the universe:

> For, any set of events that is possible according to the local laws has multiple possible futures depending on what exogenous influences impose on it. The possible futures get narrowed down to a single one only if we stipulate that there are no exogenous influences. But to say that there are no exogenous influences is a way of saying what exogenous influences there are. That additional specification is a piece of information that is only available from a transcendent perspective. It is not something that can be known from within the universe, but is fixed only once we have a full accounting of what there is. We might say that it is a piece of information about the universe, but not a piece of information in the universe. There is no more of a logical entailment from local microscopic laws to deterministic GLOEs than there is from the claim that there are five apples in the fridge to the claim that there are only five apples in the fridge. That explains why the world can be transcendently predictable, but not immanently predictable. It is transcendently predictable, because its future is determined by the local laws and initial conditions, with the additional stipulation that there are no exogenous influences.

Recall that Rummers and Cuypers (2010) comparatively suggest that a resolution to the paradox of predictability results from understanding that determinism entails *external predictability* from an external predictor making a prediction that is *not* classified as a physical event in the universe. Counterpredictive device scenarios suggest the impossibility of *embedded* predictability. Let us now see how these ideas manifest in various physical settings.

3.1 Newtonian Mechanics

Newtonian mechanics is often the physical setting associated with paradigm examples of determinism; Newtonian laws are the laws known by Laplace's demon, for example. There are however compelling reasons to think that Newtonian Mechanics is *not*, in John Earman's (1986, p.2) words, "a paradise for determinism". Earman's (1986, ch.3) argument against determinism in Newtonian Mechanics proceeds as follows. Space and time are both infinite in a Newtonian setting[9], and moreover, unlike special relativity (of which we will turn to next), the speed of material objects is unlimited. Earman asks us to consider a time slice of the universe at a particular time *t*, that is, the total state of the universe at some particular time *t*. This is a well-defined state in Newtonian mechanics given time is an external parameter; the simultaneity of events is absolute.

Earman then suggests if we select an earlier time *t** and suppose at that time a particle is accelerating towards infinity, that particle will never intersect the time slice (hyperplane) of the total state of the universe—that is, the time slice of the universe at *t*—since the speed of the particle is unlimited. As such, "even if the system is extended to include the entire universe, it is not automatically 'closed' in the operative sense to outside influences" (Earman 1986, p.34).[10]

A related argument by Ismael (2019) reinforces the problem in specifying the *total* state of the universe in a Newtonian setting. In considering some particular time *t*, Ismael (2019, p.483) first asks us to consider the set of events—let us call this S—comprising the entire history of the universe up until that time t, and moreover to consider an event—let us call this e—occurring momentarily after t. Ismael then suggests that there are "solutions to the Newtonian equations of motion that include (S)…and not e".

To obtain a solution one can add things to S which modify those forces that affect e. For any set of events occurring before *t*, there are solutions in which e occurs and solutions in which e does not occur. That which determines e is not that particular set of events in S but rather the *totality* of S. We can specify the difference between the totality of S and the set of events S as the following. The set of events S is just that: a set (or collection or assemblage) of events. The totality of S however states that the set of events is *all* there is; there are no more events to consider. If one does not specify the total, it is always possible to construct solutions by adding to the collection of pre-t events that subsequently leads to different post-t futures. Without specifying that the set of events S is *all* there is, the set of events S is left unspecified.

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[9] I have in mind a spacetime structure on a manifold as presented in John Earman's (1989) *World Enough and Space-Time*, though I take the arguments presented—pending further enquiry—to be generalizable to most Newtonian theoretical structures. See Weatherall (2021) for a helpful overview of (and recent developments in) the various classical spacetime structures. Following Ismael (2019), it may also be helpful to distinguish between different notions of determinism here too: Local Microdeterminism (LM), Causal Determinism (CD), and Laplacean Determinism (LD). LM describes (through local exchanges) the evolution of an open system as a function of its initial state and those environmental influences acting upon it. CD describes a structure in which every event is necessitated by earlier events. And LD describes a structure in which a complete spacelike hypersurface completely determines future states of the universe as a whole. LM entails LD and both hold in the Newtonian setting as described. For the reasons outlined below, CD does not follow from LM.

[10] Earman notes that this procedure also works in reverse; consistent with Newtonian mechanics are situations in which the particle *appears* from spatial infinity.

The specification that the set of events is *all* there is, that those events constitute the *totality* of what there is, can never be specified by a subsystem of the universe since "no collection of local matters of particular fact suffices to fix the total state of the world" (Ibid.). In a Newtonian setting there is nothing which places a limit on which events in the past are relevant to a particular event in the future. The possible futures that include e are only narrowed down to one future if it specified that there are no exogenous influences, namely that the set of events S is *all* there is, that the events in S comprise a *totality*. So although whilst it may be true that the total state of the universe at a particular time nomologically determines states at other times, the total state isn't fixed by a particular set of events.

The speed of light is infinite in the Newtonian setting. Let us apply the ideas above to a setting in which the speed of light is finite, namely special relativity.

3.2 Relativistic Theories

In a special relativistic setting, any spatiotemporal point p can be mapped using *light cones*.

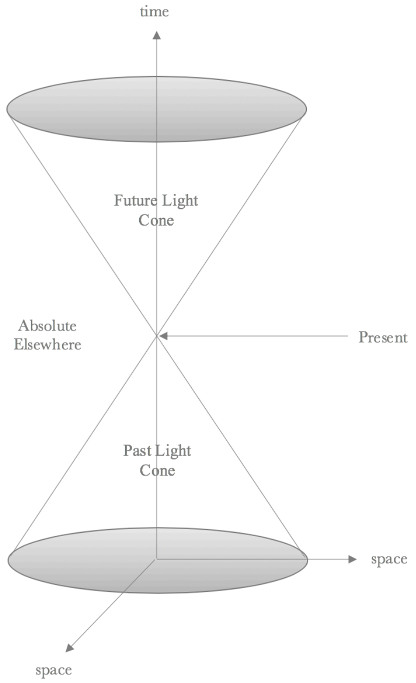

Figure 1.

The spatiotemporal structure of Minkowski spacetime (the spacetime associated with special relativity) is the light cone structure. At every point p, the light cone structure separates spacetime into three regions: the future light cone; the past light cone; the absolute elsewhere (as illustrated above). The speed of light defines the light cone structure such that for any point p, only those points in p's past light cone can influence p, and only those points in p's future can be influenced by p. The absolute elsewhere of p contain those points that cannot influence p or be influenced by p.

The light cone structure permits the explicit specification of a set of events that nomologically determine an event e. For any event in the absolute future however—call this e*—those events in the past light cone of e do not nomologically determine e*. Any cross-section of e*'s past light cone will *always* contain events that are not contained within the past light cone of e, and so influences relevant to the future event e* lie outside of e's causal past. Ismael (2019) makes this point perspicuously with the following pictorial representation—a succession of (past) light cones projected onto a surface:

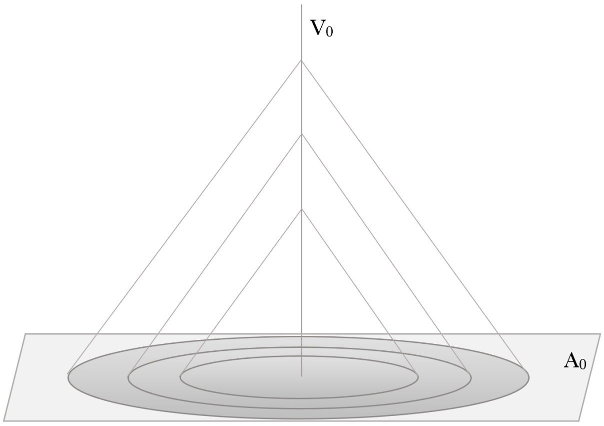

Figure 2.

If e* lies along V_0 at any point in the absolute future of e, then nothing contained within the past light cone of e nomologically determines e*. There will *always* be events contained within the cross-section of the past light cone of e* that are not contained within the past light cone of e (pictorially represented across the surface A_0). The causal past of e* intersects with the absolute elsewhere of e.

One might read this as something one could add to the list of epistemic limitations that may prohibit an embedded subsystem to predict future events in a deterministic universe (some of which are outlined in Suppes 1985; Bishop 2003). The idea is that at every stage of history, information becomes available for an embedded system, but whilst this information was not previously available even in principle for the reason outlined above, the information is *there already*, and will *subsequently* intersect the future line cone of an embedded subsystem.

However, there is no reason to think that events in the absolute elsewhere, events that are relevant to the casual past of any future point, are *there already*, or *approaching*.[11] To suppose that information is there already (its trajectory is such that it's inevitable that a light cone intersection occurs), one mistakenly imposes a conception of the past that is not consistent with the spatiotemporal ordering of Minkowski spacetime. Causal order in Minkowski spacetime can only be constructed using terms described by the light cone structure. That is, for any point p, there is a prescribed ordering that separates the set of events that fall in p's past light cone and the set of events that fall in p's future light cone. There simply is no ordering (relative to here-now) to events that lie within the absolute elsewhere. If information about the past hasn't made itself available yet, there is no sense in which we can describe that event as being there *already*.[12]

In the context of the paradox of predictability, if S is a set of events that is sufficient to nomologically determine e, and Δt is the time required for the counterpredictive process, then S cannot be causally fixed at e–Δt; the light cone structure of Minkowski spacetime is such that the set of events S isn't fixed until e. To put it another way, if *t* is the time at which the counterpredictive process begins, Δt is the time required for the counterpredictive process, and *t** is the time at which the counterpredictive process ends, then for any event in that set of events contained within the interval Δt, there are reference frames in which the event happens before *t* and reference frames in which the event happens after *t*; all the events contained within the interval Δt are only fixed at *t**.

A particularly pertinent question Ismael (2019) considers in view of this feature of special relativity is the following: can we not construct a retrospective view from the end of time? If at the end of time, one chooses an inextensible timelike curve and takes a cross section of that moment's past light cone at the relevant initial moments then will that cross section not contain the causal past of all events of the chosen world-line? There is a strong intuition that from this vantage point (so to speak), then what is revealed is a description of how events were *already* at the earliest time. However, as outlined above, events in the absolute elsewhere are *not* "already there", ready to intersect the future light cone. Those events contained within the absolute

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[11] One might suggest that this isn't the case from an *external* perspective (four-dimensional perspective or "God's-eye view) but as suggested via the discussion of Rummers and Cuypers (2010), a prediction made by an external predictor does not have a physical interpretation. The only well-defined physical description of events in Minkowski spacetime must be formulated using the light cone structure.

[12] Likewise, the causal past of a general relativistic spacetime does not fix the total state of the universe; the details of which are a little more technical, however. Intuitively, we can string out a collection of points in a GR spacetime (the so called "clothesline construction") and add events in between each point to give a different solution to the laws. See Manchak (2009) for details.

elsewhere simply aren't fixed, and those events that are "nomologically necessary to fix a future event e", in Ismael's (2019, p.487) words, "are no more or less fixed that e itself."

Consider figure 2 again for a particularly helpful way to see this. The information contained between two points represented along V can also be represented across the surface between the corresponding light cones of those two points. And so if at the end of time, we take a cross section of the very last moment's past light cone, the information contained across the surface is in fact information which is extended across the entire temporal dimension between the first and last moments, prompting Ismael (2019, p.488) to write: "Information about the total state of the universe along the spatial dimension in the past that is needed to fix its future *is information from the future.*"[13] Or to put it another way, if one tries to capture information which spans all of space, this is information which also spans all of time. Moreover, the cross section of the very last moment's past light cone is not sufficient to generate a truly *global* position; to generate a global point of view, one requires a cross section of the very last moment's past light cone for *all* inextensible timelike curves in the universe. As such, it turns out that there is no global point of view of spacetime from an embedded perspective.[14]

Whilst it may be commonplace in theoretical practice and pedagogy to include a global view of spacetime, a global present, or to consider events in the absolute elsewhere as ordered, these notions are explicitly *not* consistent with relativistic physics. For any embedded subsystem of the universe, events that occupy the absolute elsewhere, in Ismael's (2019, p.488) words, "are literally *nowhere*", they are no more in the past than in the future and only acquire a position when the relevant light cones intersect. And given we cannot give a physical interpretation to a system which lies outside or *external to* the universe, one must concede that events as described by an *embedded* subsystem is the only physically meaningful perspective from which one can understand the total state of the universe.

It is important to acknowledge how the arguments presented here relate to particular views in the philosophy of time. There are broadly two camps in the philosophy of time, those who advocate the passage of time, namely *temporal becoming*, and those who suggest that the passage of time is 'illusory'[15], instead advocating a *block universe* theory of time, which proposes

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[13] Ismael is careful to distinguish "information *about* the future" and "information *from* the future". The former is derived by applying laws to the past whilst the latter simply cannot be acquired: "It is like information from crystal balls" (Ismael 2019, fn.17).

[14] There are however general relativistic spacetimes in which the whole spacetime falls from a particular point. Even so, the causal past of a general relativistic spacetime does not fix the total state of the universe (see footnote 12 above).

[15] The term 'illusory' is often referenced to Einstein's letter of condolence to the family of his good friend, Michele Besso, upon his passing. Einstein writes: "Now he has departed from this strange little world a little ahead of me.

a 'fixed' four-dimensional block of all events. The notion of a 4-dimensional block universe that details every event at every spacetime location would seem at least *equivalent to* totality. Thus if the notion of totality is incoherent as suggested above, then—it may be argued—the notion of a 4-dimensional block universe is also incoherent. *Prima facie,* this is a radical consequence of the physical anti-absolutist view, and is therefore one that deserves attention.

Firstly, I think one must be careful about the way in which the block universe is described. Its nomenclature and frequent pictorial representations as a 'grid' or 'block' of events suggests that the block universe is *fixed*, or *static*, or *frozen*. However, such notions are used to describe objects which do not change over time; to describe an object as fixed, or static, or frozen is for that object to be embedded in time (and of which its form remains unchanged throughout). To describe the block universe with notions such as static or fixed—if intended in this way—is inappropriate since by describing the block universe as static or fixed, one must appeal to some 'hyper-time' of which it remains unchanged in relation to. This is a point emphasised recently by Maudlin (2018):

> I believe that it is either false or a hopeless misuse of words to say that the block universe, i.e. all of the past, present and future, is "frozen" or "static" since those qualities only pertain to entities that persist through time and the whole of space-time does not itself persist through time. The whole of space-time is not in time at all: time (temporal structure) is in it.

Relatedly, in response to claims that—according to relativity—the future is *there already*, Ismael (2021, p.29) comparatively argues that "the fact that the 4D image isn't changing does not mean that it is not an image *of* change" (see also Ismael 2016 ch.5). This mistake Ismael is pointing to has, I think, been reinforced by the metaphor of a block, or grid. Writing nearly a century ago, James Jeans (1935) evocatively compares spacetime to a "tapestry that is already woven throughout its full extent…so that the whole picture exists, although we only become conscious of it bit by bit—like separate flies crawling over a tapestry." Again however, the metaphor suggests that the spacetime "tapestry" *and* the flies that crawl over it are embedded in time—this is precisely why it's regarded as a "tapestry that is already woven throughout its full extent" since its form fails to change over time, in contrast to those flies which crawl over it. A perspicuous description of the block universe is one that acknowledges *and resists* the temptation to adopt an exogenous perspective from which the block universe—and all of its contents—

That means nothing. People like us, who believe in physics, know that the distinction between past, present and future is only a stubbornly persistent illusion" (Einstein and Besso 1979). However, it's not clear to what extent this statement is Einstein's philosophical position or just an encouraging word to a family in grief.

comes into view. In describing the block universe as a static structure of events, we adopt a view of time that has no physical correlate (of which the block is embedded); the only physical description of time is that which is contained *within* the block.

Secondly, and more pertinent to *physical anti-absolutism*, is the idea that the block universe has boundaries, is *complete*, and constitutes *all* events. If one accepts that it is inappropriate to describe the block universe as 'static', this removes at least one possible reason for thinking that the block universe is complete. There are undoubtedly other reasons for thinking that the block is complete but the suggestion that the block might be *incomplete* seems at least *prima facie* a possibility. Moreover, the true insight of the block universe view—as I understand it—is moving from a three-dimensional to a four-dimensional understanding of reality, and there seems to be no tension from incorporating that insight into the physical anti-absolutist picture. Rather than space and time being separately incomplete, spacetime is incomplete.

Representing the universe as a fixed, complete set of events, loses all contact with the contingency of the universe's evolution, and mistakenly appeals to a distinctly *unphysical* view from which to make it the case that the future is *already there*. Such representations suppress all those ideas pertinent to this section, namely that those events in the absolute elsewhere are only ever fixed once relevant light cones intersect. As I see it, the notions of the block being fixed or having borders are not necessary features of the view, but are rather notions that have been conflated with the idea by appealing to erroneous features and limitations of popular representations. The block universe can still be a block, but it is one in which time is endogenous, and as such 'the future' is never there already.

Lastly, it may simply be the case that a consequence of accepting *physical anti-absolutism* is a firm rejection of the block universe—or at least a radical rethink of the view. I think this is unlikely but it's worth noting that perhaps it will turn out that a particular frame of reference is preferred or that, for example, as Lee Smolin (2013) suggests, timeless physical laws are replaced with physical laws that evolve—a fact that would be difficult to incorporate into a 'block' representation.

The link between the block universe and totality is an underdeveloped area of research and is one that should be of interest both to those in the (meta)physics of totality and those in the philosophy of time. I hope, however, to have at least suggested reasons why the block universe and physical anti-absolutism are not necessarily in tension with each other.

Let us briefly return to the metaphysics before considering quantum theory. Recall from the metaphysics of totality discussion that Russell's paradox and Dummett's indefinite extensibility (§2.2) provide at least some motivation for thinking that for any collection of objects, one can always use that collection to characterize more. If one accepts this feature, one natural conclusion is that there is no sense to be made of an all-inclusive domain. The above examples illustrate how this idea can be implemented in different physical settings.

As discussed in chapter 2, there are major obstacles in characterizing a totality of all sets, or all ordinal numbers, or all facts or truths. One lesson to draw from these results is that we should be sceptical of the assumption that a syntactically coherent description of a purported totality (e.g., the set of all sets) refers to something that is actually coherent. This feature extends directly to the respective domains of the physical theories cited above. The Laplacean intelligence is a good case in point; the hypothetical examination of *every* particle position together with *all* physical laws constitutes a coherent and syntactically coherent description of a totality. But a detailed evaluation of the physics gives rise to the realisation that for any embedded system, it is not simply the case that there are epistemic limitations on the availability of information about the total state of the universe, but rather that there are explicit reasons which undermine the total state as a (meta)physically coherent concept. In a Newtonian setting, there is no way to specify the collection of events that is sufficient to nomologically determine events at other times. In a relativistic setting, the global point of view from which it seems that there is a fact—at this moment—about the state of the universe as a whole, is explicitly disallowed.

Interference Effects

The second part of Ismael's (2019) resolution to the paradox of predictability concerns, in her words, "*interaction*" or "*interference*"[16] effects. Considered in logical terms, the predictor cannot make a successful prediction since "the nomological determinants of the predicted event includes the prediction itself" (Ismael 2019, p.490). The relation between the prediction and the predicted event is one that makes a correct prediction impossible. In other words, the prediction *negatively interferes* with the event predicted.[17]

Ismael suggests a couple of ways to generate a similar sort of situation. First, imagine one writes a deterministic, counterpredictive computer program (however simple) and subsequently attempts to predict the outcome under the constraint that one's prediction is revealed to the computer. One way to do this is to simulate the program, which will reveal the input,

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[16] The term, interference, as used here is not to be confused with interference patterns as described in §3.3.

[17] In contrast to Scriven's suggestion, Ismael's notion of interference does rely on the prediction being revealed (or to be more specific: that that all calculational routes are setup such that it is a nomological necessity that information from initial data to predicted outcome passes through the prediction).

but the simulation output, namely the prediction, is input to the computer program. The prediction itself negatively interferes with the predicted output. Compare this case to an oracle, perhaps a Laplacean intelligence attempting to make a prediction. If the route by which information from the source data to the predicted outcome always moves through the prediction, then the calculation will always fail since the prediction will negatively interfere with the predicted outcome.

An even sharper way to generate negative interference, Ismael suggests, is to ask a hypothetical oracle (with an output display) the following: "Is the answer to this question that is about to be displayed on the output channel 'no'?" One quickly realises that there is no way to correctly answer this question. In giving an answer, one undermines the prediction; in Ismael's (2019, p.491) words, "the prediction *does* the opposite of what it *says*."[18]

The paradox of predictability is set up in a comparable way. So long as the prediction (conceived of broadly in whatever form it happens to take) is connected to the domain it predicts and that all calculational routes are setup such that it is a nomological necessity that information from the source data to predicted outcome moves through the prediction, then negative interference will always result.

We can see the connection here with *external* and *embedded* predictability. What external predictability allows is a route from initial data to the predicted outcome that *doesn't* move through the prediction. As suggested above however, this can't be a *nomological* route since this route has no physical correlate. The status of a prediction made from a hypothetical observer positioned outside the universe is unequivocally non-physical, and so there isn't a nomologically sufficient route that permits information to pass in this way. If a system cannot be separated from the domain it intends to describe, that is, if predictions about a domain create disturbances in the domain, there will be limitations on predictability, despite a deterministic setting.

Ismael suggests that we can exploit interaction effects to create a desirable future—we have the ability to affect the future—the upshot here however, for the *physical anti-absolutist* is to illuminate difficulties in being able to stabilize totality as an object of knowledge. There are physical constraints for any system embedded within the universe to specify the total state of the universe.

We will revisit this idea when I discuss quantum theory and interference in §3.7. For now, let us now sketch the necessary physics in order to discuss quantum theory and totality.

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[18] Original emphasis.

This will setup the discussion of the more technical issues surrounding totality and the physics of open and closed quantum systems in the following section (§3.8), and the arguments set out in chapter 4 (quantum mechanics and objectivity).

3.3 Quantum Theory

Quantum mechanical experiments have delivered a consistent and accurate match for the mathematical formula (e.g., the Stern-Gerlach experiment or the double-slit experiment—the details of which I describe in this section). Whilst being able to make predictions at a microscopic level, there is at least the appearance of a genuine contradiction, between the world observed at the level of fundamental particles and the world observed in our everyday experience. A helpful starting point is a description of the *double-slit experiment*.[19]

"Double-path" experiments had been performed long before the theory of quantum mechanics was suggested. In 1801, the polymath Thomas Young performed an experiment using sunlight to illustrate light's wave-like properties. Over a century later, Davisson and Germer (1927) demonstrated the same behaviour for electrons scattered by the surface of a crystal of nickel metal. The modern apparatus for the double-slit experiment is something like the following:

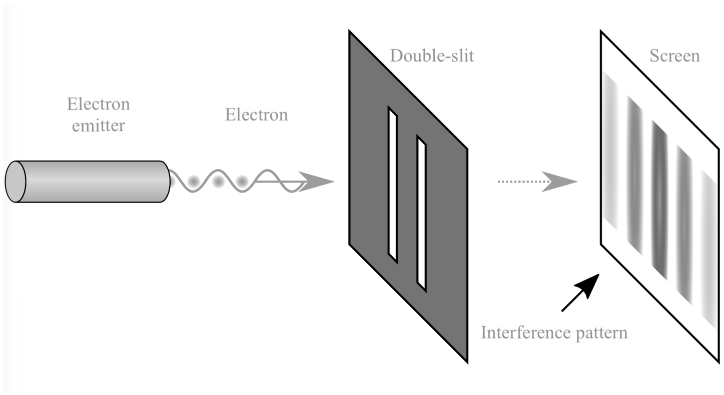

Figure 3.

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[19] Whilst there are alternative ways to present quantum theory, double-slit experiments are often used to illustrate quantum phenomena. This is, I think, a helpful place to start for my presentation of quantum theory (and my subsequent presentation of EQM).

Consider a single electron emitted from an electron emitter. Given the apparatus above, and without knowledge of quantum mechanics, one may naturally expect the electron to impact the screen at some location behind one of the two slits. After a number of electrons are emitted, there is reason to expect the screen to indicate a distribution of electrons in roughly two areas.

This is not the case, however. After a sufficient number of (individually emitted) electrons have passed through the double-slit, an interference[20] pattern is visible on the screen. One way to make sense of this behaviour is to assign wave-like properties to electrons. In the case described above, the electron (exhibiting wave-like behaviour) passes through *both* slits; the interference of the two waves (corresponding to each slit) results in an interference pattern visible on the screen behind the double-slit.

If a detector is then positioned on each slit in the hope of tracing the path of an emitted electron, or in the hope of finding out whether each individual electron splits in two as it passes through the double slit, we always find that the electron is detected at one slit or the other, and never find any evidence for 'splitting' (see Rae 2004, p.9-10). Similarly, if a shutter is positioned behind each slit such that only one slit is open at a time, the interference pattern is destroyed. It would then appear that introducing a detector (or a shutter) to the experimental setup is associated with the electron exhibiting particle-like behaviour. *Prima facie*, one may conclude the following: an electron passing through a double-slit without detectors exhibits 'wave-like' behaviour and an electron passing through a double-slit with detectors exhibits 'particle-like' behaviour.[21]

3.4 Prerequisite Concepts

Before discussing the significance of this result, let us sketch a brief overview of the physics that will prove useful for subsequent discussion.

The Wavefunction

Quantum mechanics is done in *Hilbert space*—a mathematical (complex and multidimensional) space in which the possible states of a quantum system are represented by vectors. A *wave function*

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[20] Recall that this is distinct from the type of interference discussed in §3.2.

[21] This phenomenon (sometimes described as 'wave-particle duality') prompted Bohr's (1958) 'complementarity' notion.

(represented as psi: ψ) is a mathematical description of the state of a quantum system, given as a complex-valued probability amplitude. An *observable* is a measurable physical quantity, such as *position* or *momentum*.[22] The *Hamiltonian* of a system specifies its total energy. Given a chosen observable, the wave function is a function of the degrees of freedom with respect to that observable. If we consider the position state of a particle in one dimensional space for example, it's possible to represent the particle's position state by a function. The function in this case takes the point in that space (i.e., somewhere on the one-dimensional infinite line that we have specified) as its input and gives a complex number as its output (wave function amplitude). The function may represent the particle being determinately located at a particular position along the one-dimensional line or may represent a particle that is in a *superposition* (this will be elaborated in due course) along the one-dimensional line.[23] The evolution of the quantum state is given by the Schrödinger equation:

$$i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle = H|\psi(t)\rangle$$

The equation is deterministic and linear. Evolving the quantum state according to the Schrödinger equation at one time will determine the state at any other time. A *basis* is defined by a linearly independent and complete set of vectors in Hilbert space. The (ideal) measurement of a quantum system is carried out with respect to a particular basis. Consider the evolution of a quantum state, represented mathematically by two vectors in Hilbert space.[24] The vectors, $|\psi_1(0)\rangle$ and $|\psi_2(0)\rangle$ evolve respectively to another quantum state represented by two vectors, $|\psi_1(t)\rangle$ and $|\psi_2(t)\rangle$. More formally:

$a|\psi_1(0)\rangle + b|\psi_2(0)\rangle \rightarrow a|\psi_1(t)\rangle + b|\psi_2(t)\rangle$

If the state depicted at time 0 is a linear combination of $|\psi_1(0)\rangle$ and $|\psi_2(0)\rangle$, the state at (any) time *t* will be the corresponding linear combination of the state $|\psi_1(t)\rangle$ and $|\psi_2(t)\rangle$. If the quantum state evolves in accordance with a linear equation (i.e., the Schrödinger equation),

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[22] The state of the system with respect to a measurable physical quantity is sometimes called an *eigenstate*.

[23] . See Alyssa Ney's (2013a) introduction for a helpful overview of this topic.

[24] In standard bra-ket notation.

the formalism tells us that there are distinct quantum states that are *combinations of experimental outcomes*, otherwise known as *superpositions*. Let us call this the superposition principle.

Decoherence

Consider the double-split experiment again. Given we can represent a particle's trajectory by a vector corresponding to either the left slit or the right slit, the superposition principle gives us a particle's state to be a superposition of 'trajectories' through the left slit *and* the right slit. The total wave function for an electron passing through the double split apparatus above can be written by summing both component states, each of which is assigned a probabilistic weighting (written as a coefficient):

$$\psi = \frac{1}{\sqrt{2}}|electron\ passes\ through\ left\ slit\rangle + \frac{1}{\sqrt{2}}|electron\ passes\ through\ right\ slit\rangle$$

A state's *phase relations* mathematically express the combination of amplitudes corresponding to the component states of the superposition. If the phase relationship is constant, the system will exhibit interference effects[25] and the state may be described as a coherent superposition. If a quantum system's phase relations are delocalized (from interacting with external degrees of freedom such as its environment, for example), interference is suppressed. *Decoherence* is the process of *decohering* the phase relations—the process of losing coherence—between the component states of a quantum system's wavefunction.[26]

Entanglement

An *entangled* system can be defined as a quantum system whose state does not factor into the states of its constituent systems. If a quantum system *S* becomes entangled with its environment *E*, we cannot provide a description of the quantum system *S* independently of its environment *E*; the system's phase relations delocalize and decohere (into the environment's new degrees of freedom). Crucially, the system's environment can be defined as any degrees of freedom apart from those being considered (for example, if particle 1 and particle 2 are entangled, one can

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[25] That is, an interference pattern will appear on the screen.

[26] For further details of decoherence, see Wallace (2012 Ch.3) and references therein. For a helpful overview, see Crull (2013).

consider particle 1 as the system and particle 2 as the environment). Entanglement is pervasive in the following sense. When a system becomes entangled with its environment, the Hilbert space of the system combines with the Hilbert space of the environment; the coherence of the (initial) system's phase relations 'leaks' into the combined Hilbert space. The composite system gains coherence whilst the initial system loses coherence— its phase relations become delocalized and decohere into the environment's degrees of freedom. This composite system then becomes entangled with *its* environment and decoheres, whilst the new composite system gains coherence.[27]

Interpretations

The quantum formalism suggests that there are quantum states which correspond to combinations of experimental outcomes, but the empirical evidence of the quantum experiments—including the double-split experiment above—would suggest that only one outcome obtains post quantum measurement. If we take the quantum formalism seriously (or 'literally'[28]) and accept that systems can be in distinct quantum states which correspond to combinations of experimental outcomes, there is reason to think that a quantum measurement tells us about a reality in which multiple distinct experimental outcomes obtain. If on the other hand we give more consideration to the idea that quantum experiments lead to single, distinct outcomes, there is reason to think that quantum measurements tell us about a reality in which only a single distinct outcome obtains. We can put the distinction in terms of the conjunctions *and/or*: is quantum mechanics a theory that predicts experimental outcome *x or* experimental outcome *y*, or is quantum mechanics a theory that predicts experimental outcome *x and* experimental outcome *y*?

If the former is correct, we may also use wave function amplitudes to describe a relationship between the wave function of a system and the expected observational outcomes of that system. The Born rule (Born 1926) says: the probability of obtaining any possible measurement outcome is equal to the square of the corresponding amplitude.[29] Thus given the

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[27] This is why the cosmos is often treated as an entangled system (as discussed in §1.7).

[28] A term endorsed by Wallace (2012) and explored in §4.2.

[29] If reality is such that outcome *x* and outcome *y* obtain, then attaching a probability to each outcome is more controversial: given both outcomes obtain, to what is it that we are attaching probabilities? I discuss this and related problems in chapters 5 and 7.

respective amplitudes of possible outcomes *x* and *y*, one can calculate—via the Born rule—the probability of outcome *x* obtaining and the probability of outcome *y* obtaining.[30]

One way to explain how the post-measurement empirical observation of a single, definite outcome results from the pre-measurement quantum states that are combinations of experimental outcomes is by endorsing a so-called *collapse* of the wave function. Collapse models of quantum theory have been formulated in a number of different ways (see Ghiradi and Bassi 2020) but one long assumed way for a quantum state describing a combination of experimental outcomes to reduce to a single empirically observed outcome is for the wave function to always collapse when a measurement is made.[31] Thus we can say:

1. Quantum states can be represented by wave functions.
2. Wave functions are represented by vectors in Hilbert space.
3. Wave functions evolve in time according to the linear Schrodinger equation.
4. The Born Rule says the probability of returning a particular (eigen)value, i.e., the probability of obtaining a possible measurement outcome, is equal to the square of the amplitude for that (eigen)value.
5. Up until the measurement is performed, the system is in a *superposition* of states. After the measurement, the wave function *collapses* into a new state.

The collapse picture can account for the double-slit experiment that I began this section with. Recall that an electron passing through a double-slit without detectors exhibits 'wave-like' behaviour and an electron passing through a double-slit with detectors exhibits 'particle-like' behaviour. The process of measuring the electron, exemplified in our case by the detectors on the double-slit screen, *collapses* the wavefunction. Pre-measurement, the electron is described as being in a superposition of states; the process of measuring then collapses the electron into a new state with a definite position—observed as either going through the left slit or the right slit.

We can also express the above setup using the following terms:

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[30] More formally, given a system is prepared in state $|\psi\rangle$, the Born rule tells us that, upon measurement, the probability of finding the system in an eigenstate of an observable A, is given by: $|\langle\alpha|\psi\rangle|^2$.

[31] This way of understanding quantum theory is often associated with the 'Copenhagen Interpretation' devised and defended predominantly by Niels Bohr. The history of which is a complicated one; there have been wide and varied interpretations associated with this nomenclature and specifying exactly what one means by the 'Copenhagen interpretation' is a substantial project in itself (see for example Gomatam 2006 or Howard 2002). Moreover, whether there is a way to give enough precision to the term 'measurement' is still a contentious topic today. For ease of presentation, and since my main focus will be on EQM, I avoid many of the details in the above description.

$$\psi = \frac{1}{\sqrt{2}}|electron\ passes\ through\ left\ slit\rangle + \frac{1}{\sqrt{2}}|electron\ passes\ through\ right\ slit\rangle \rightarrow$$

$$\psi' = \frac{1}{\sqrt{2}}|electron\ passes\ through\ left\ slit\rangle \text{ with probability } \frac{1}{2}$$

or

$$\psi' = \frac{1}{\sqrt{2}}|electron\ positioned\ at\ right\ slit\rangle \text{ with probability } \frac{1}{2}$$

In this case, a system collapses onto states which have determinate values with probabilities given by the Born rule.[32]. For any measurement of a quantum system, quantum physics also applies to the measurement device, described unitarily in terms of evolution on Hilbert space. The measurement device itself is thus predicted to evolve into a superposition of macroscopically distinct states, which is of course at odds with the (apparent) single, definite states of measuring systems. Moreover, considering agents interact with measuring devices, one must also predict the evolution of agents into a superposition of macroscopically distinct states, which is (also) inconsistent with our experience of the world.

The difficulty in finding a way to reconcile the description of reality that the formalism gives us with the experimentally definite results of macroscopic instruments is known as *the measurement problem*—the mutual exclusivity of states we associate with pre-quantum theory seems to be violated by (quantum) superposition of states.[33] This is what led to John Bell's (1987, p.201) widely cited proposition: "Either the wavefunction, as given by Schrödinger's equation, is not everything, or it is not right." Schrödinger could not account for "the definiteness, the particularity, of the world experience, as compared with the indefiniteness, the waviness, of the wavefunction", famously exemplified by Schrödinger's—dead and alive—cat.[34]

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[32] For such an experimental setup, there are other outcomes that may obtain (e.g., the experiment may fail altogether) but for simplicity, I consider only the two specified.

[33] There are of course other proposals that attempt to resolve the measurement problem. Notable interpretations include *Bohmian mechanics* (sometimes known as *pilot-wave theory*), originally proposed by Louis de Broglie (1927) and rediscovered by David Bohm (1952a, 1952b), and spontaneous-collapse theories such as the GRW theory (Ghirardi *et al.* 1986). However, my primary interest here is an approach that does not add anything qualitatively new to the minimal quantum ontology. I take EQM to be a good candidate for such an approach and therefore direct my attention there.

[34] Schrödinger (1935).

3.5 Everettian Quantum Mechanics[35]

Recall in the previous section, I contrasted two ways one may think about quantum theory: is quantum mechanics a theory that tells us about a reality that consists of experimental outcome *x or* experimental outcome *y*, or is quantum mechanics a theory that tells us about a reality that consists of experimental outcome *x and* experimental outcome *y*? Consistent with the former of these two approaches is wave function collapse, which gives an account of how the experimentally definite results of macroscopic instruments obtain from the description of reality according to the mathematical formalism. The process of measurement collapses the wavefunction into a new state; the direction of the measurement pointer indicates *either* outcome *x or* outcome *y* obtains.

What does reality look like on the latter picture, namely one that does not attempt to extract a single state from a superposition after measurement, and rather proposes a reality in which experimental outcome *x and* experimental outcome *y* obtain? Such was the task of Hugh Everett III's (1957a) Princeton doctoral thesis. Two years earlier whilst drafting his thesis, Everett wrote a number of (unpublished) short papers, one of which ('Probability in Wave Mechanics', 1956 p.4) reveals an intuitive account of his reasoning:

> Why doesn't our observer see a smeared out needle? The answer is quite simple. He behaves just like the apparatus did. When he looks at the needle (interacts) he himself becomes smeared out, but at the same time correlated to the apparatus, and hence to the system. If we reflect for a moment upon the total wave function of the situation system-apparatus-observer…we see that for the definite system value x_j the needle has definite position y_j, and there is a *definite observer* who perceives that the needle has the definite position y_j…In other words, the observer has split into a number of observers, each of which sees a definite result of the measurement.

A superposition of a particle located at position *x* and a particle located at position *y* is represented by a state vector associated with being at a point *x plus* a state vector associated with being at point *y*. Suppose the pointer is orientated left if the particle is at location *x* and orientated right if the particle is at location *y*. The theory predicts the following post measurement state:

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[35] Although this section contains some relevant history of Everett and the initial formulations of his theory, my focus in this thesis is on contemporary decoherence-based EQM, central to the arguments of Deutsch, Greaves, Saunders and Wallace (references throughout).

a particle is at location ***x*** *and a pointer is orientated left and a sentient observer perceives a measuring device pointer to be orientated left*

+

a particle is at location ***y*** *and a pointer is orientated right and a sentient observer perceives a measuring device pointer to be orientated right*

For an agent about to make a quantum mechanical measurement, how can it then make sense to isolate a single outcome as the result of a particular experiment, given there are branches in her future where each measurement result is displayed on the measurement apparatus and she is there to observe it?[36] Everett (1957b, p. 317) proposed "a fundamental *relativity of states*…it is meaningless to ask the absolute state of a subsystem—one can only ask the state relative to a given state of the remainder of the subsystem." Rather than multiplying individual systems, Everett multiplied the relative states of individual systems; the state of a system is only *actual* relative to the state of some other subsystem. In the case above, the sentient observer perceives a measuring device pointer to be orientated left relative to one substate and perceives a measuring device pointer to be orientated right relative to another.[37]

Throughout the course of his PhD, Everett showed signs of hesitance in committing to the radical metaphysics implicit in his theory (See Barrett 2011 for a comprehensive account). Often using scare quotes around words such as "other selves" and physical "reality" (1956 p.6 and p.7), Everett opted to talk in terms of relative states rather than many worlds. Diverting attention away from the observer-system to the observer's states enabled Everett to maintain a description of a single physical observer but for whom multiple relative states obtain post-measurement. In adopting such a strategy however, Everett now had the problem of resolving the relativistic metaphysics inherent in relative states (see Barrett 1999 and Conroy 2012 for suggestions of how to develop this approach); there may be reason to think that developing the theory as a theory of multiple worlds might not be so metaphysically radical after all.

Everett showed sympathy towards the idea of multiple worlds a few years after receiving his doctorate (see Werner 1962) but omitted such language from his final thesis; instead it was Bryce DeWitt's (1968, 1970) presentation that popularised the theory as one that describes many worlds. DeWitt still had to show how one can extract multiple worlds from the

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[36] The metaphysics of personal identity in EQM is addressed in ch.7.

[37] Conroy (2012) gives an insightful review of Everett's preferred interpretation of his theory.

mathematical formalism alone, however.[38] As Adrian Kent (1990 p.11) suggests, we may be able to intuitively associate the components of the wave function as representing two (independent) worlds, but "this intuitive interpretation goes beyond what axioms justify: the axioms say nothing about the existence of multiple physical worlds corresponding to wavefunction components."

Branching and Decoherence

We can (as Everett's formulation of the theory did) presuppose that the wave function is decomposed into a 'preferred' set of physically observable quantities (a *preferred basis*). However, stipulating a preferred basis runs contrary to the theory's conservative and realist solution to the measurement problem, and so technical work in *decoherence* in the early 1990s[39] led to a reading in which the selection of one basis over another can be accounted for by the dynamics of the system itself. In decoherence-based EQM, the process of decoherence includes the (approximate) selection of a preferred basis, suppressing interference to a degree sufficient to explain the fact that macroscopic superpositions are unobserved (and unobservable). And so given the conditions of decoherence are only satisfied to a high degree of approximation (that is, interference is not suppressed entirely), Everett worlds are not completely qualitatively determinate. Structures properly construed as physically real worlds are understood as *emergent* entities, identified as decohered components of the quantum wave function (satisfied to a high degree of approximation). Everett worlds are not defined in microscopic terms, they are emergent structures—patterns in the fundamental quantum state—that are to be understood using concepts of emergence in the physical sciences more broadly.

Divergence/Overlap

There are two metaphysical pictures associated with the structure of worlds in EQM. If we take those entities represented by a particular projection operator[40] appearing in two different consistent histories as numerically identical, we are given *overlapping* Everett worlds. If on the other

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[38] De Witt (1970, pp.160-161) suggests that "the mathematical formalism of the quantum theory is capable of yielding its own interpretation" and that it "forces us to believe in the reality of all the simultaneous worlds represented in the superposition…in each of which the measurement has yielded a different outcome".

[39] See e.g., Saunders 1993, 1994, 1995.

[40] For a helpful discussion of projection operators in this context, see Wilson (2020, ch.2).

hand, those entities are (numerically distinct) qualitative duplicates, we are given *diverging* Everett worlds.[41] Either picture is an available metaphysical option for the Everettian; the formalism remains the same but can be interpreted either way. The following illustrations (Figure 4) are often used to schematically represent the respective Everettian metaphysical pictures, which should help clarify why overlap (and not divergence) gives rise to notions of splitting or branching.

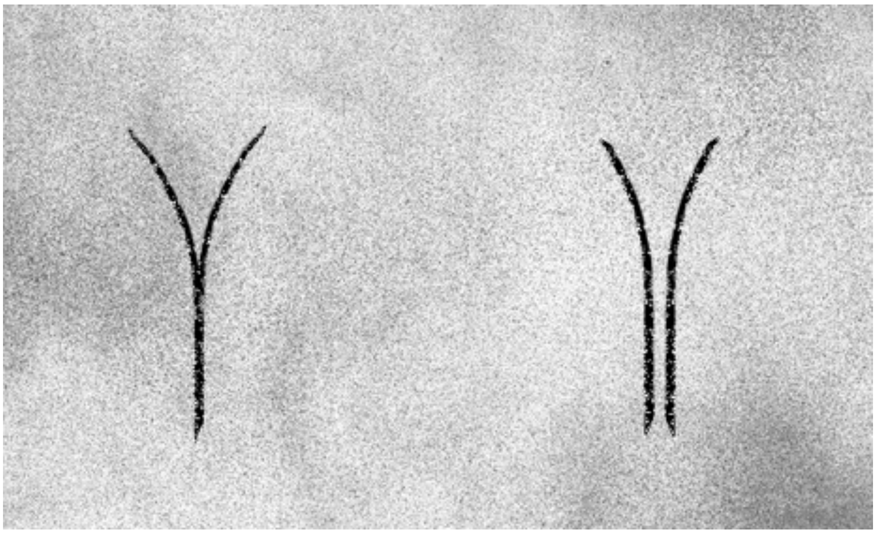

Figure 4. Overlap (left); Divergence (right).

The Analogy with Fission

Given the sense of 'splitting' suggested by the overlap metaphysical picture, Parfittian (1984) arguments from 'fission' cases are often utilized in discussions of Everettian quantum mechanics in an attempt to illuminate details of an Everettian agent who performs a quantum measurement (and subsequently 'splits'). Fission cases have predominantly been brought into EQM discussion to help illuminate problems concerning probability. Wallace (2003b) introduces the terms *incoherence problem* and *quantitative problem* to describe two strands of the probability problem

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[41] Whilst I assume that both *overlap* and *divergence* are available metaphysical pictures in the Everett interpretation, I consider this assumption to be aligned with contemporary EQM literature. For those sceptical of divergence: Saunders (2010b) and Wilson (2011, 2020) suggest divergence is not only viable but a preferred metaphysical reading of EQM. Sebens and Carroll (2018 fn.4) acknowledge their strategy can be implemented on either overlap or divergence. Despite questioning diverging Everett worlds, Tappenden (2019b, §5) recognises its appeal, devoting a whole section to the view. The view is considered in similar detail in Tappenden 2019a. Gomes (2018, p.703) may also be read as proposing a diverging worlds approach (despite not adopting the terminology): "To be more precise, nothing is splitting, all the individual copies of the system already exist in timeless *Q*."

in EQM. Firstly, given that all possible outcomes of experiments are realised in some post-measurement branch, how can we speak of probabilities at all? (*Incoherence problem*). And secondly, even if it's coherent to assign probabilities to the outcomes of measurements, why should these probabilities be given by the Born rule? (*Quantitative problem*).

Greaves (2007) introduces a term to describe a further aspect of the problem[42]: the *epistemic problem* asks how our empirical evidence is justified according to EQM. Authors have attempted to address these problems in a number of ways, often underpinned by the foundational metaphysics of Parfittian fission scenarios.

Whilst no longer endorsing the view[43], Saunders (1998 p.385) appears to be one of the first to propose the analogy in an Everettian context, introducing the familiar thought experiment in which "persons can be symmetrically split into two, without any psychological disturbance or loss of memory". Though Saunders doesn't use the term, he proposes that Everettians can rationally adopt an attitude of what has subsequently been called *subjective uncertainty* regarding future branching. He proceeds by analogy with fission aiming to demonstrate that the question, "which future self should I expect to become?" is subjectively indeterministic. For lack of a legitimate reason to favour one successor over the other, the pre-fission agent "should expect to become one or the other with equal likelihood". The analogy is sufficient, argues Saunders, to be carried over to EQM: "the similarities between this and the quantum mechanical case are evident."

Following pioneering work by Deutsch (1999), Wallace (2003b, 2006) sets out to prove the decision-theoretic link between objective probabilities and rational action. Given a set of decision-theoretic axioms, one can derive appropriate decision theories for Everettian agents. With the help of Saunders' fission thought experiment, Wallace argues that objective probabilities are synonymous with Everettian branch weights, which quantifies alternative possibilities, and thus subjective uncertainty.[44]

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[42] Greaves also introduces the *practical problem*: why should we allow quantum probabilities to rationally guide our actions? For my purposes, I address only the three aforementioned components of the probability problem.

[43] Saunders' current view is explicated in Saunders (2010a, 2010b), which will be addressed in the forthcoming sections.

[44] Wallace (2003b, p.417) suggests: "In my view, the most promising approach is Saunders' 'subjective uncertainty' theory of branching: Saunders argues (via the analogy with Parfittian fission) that an agent awaiting branching should regard it as subjectively indeterministic. That is, he should expect to become one future copy or another but not both, and he should be uncertain as to which he will become." Moreover, "The idea of subjective uncertainty…was originally proposed by Saunders (1998), who argues for the SU viewpoint by means of an ingenious intuition pump. His argument proceeds by analogy with "classical splitting", such as that which would result from a Star Trek matter transporter or an operation in which my brain is split in two." (Wallace 2006, p.664).

Greaves (2004, 2007) on the other hand denies that objective probability makes sense in Everett's theory. Her *fission-based interpretation* borrows from Deutsch and Wallace, applying a decision-theoretic strategy to an agent in terms of the *care* she has for her future selves. Assigning objective probabilities to branch weights, according to Greaves, does not make branches with a high Born rule weight any more likely to occur—to the contrary, all outcomes occur. But an agent does, in contrast to Parfittian fission, have a *caring measure* over her successors in EQM, and so can rationally assign differential care values for future branches.

This sets Greaves apart from Saunders and Wallace, rejecting subjective uncertainty, and instead proposing an argument for *subjective certainty* (2004, §4.1.3). For Greaves, there is no fact of the matter about what an agent's *unique* successor will observe post quantum measurement and so the question "what will the agent see?" is badly posed. Instead, her proposal suggests the pre-branching agent "should (with certainty) expect to see spin up" and the pre-branching agent "should (with certainty) expect to see spin down", concluding, "Not that she$_1$ should expect to see *both*: she$_1$ should expect to see *each*." (Greaves 2004 p.441). On this reading, despite there being no uncertainty, it is still rational for an agent to differentially attribute a measure of care over her future selves. In chapter 7, I suggest that the fission analogy encourages a reading of EQM through the lens of reality as we know it, undesirably importing features of the ordinary world into a very different physical setting; it encourages one to export conceptual machinery relevant to our own experience into a domain which isn't constrained by such features.

World Number

Everett worlds result from the discretization of configuration space but a modification to the coarse-graining of the decoherence basis will alter the enumeration of worlds. If the partition is chosen at a particularly fine-grain, more worlds will be counted than if the partition is chosen at a coarser-grain. The choice of grain is not without limit however: if the description is either too coarse-grained or too fine-grained then the decoherence conditions will cease to be met—but there is no precise point at which these conditions occur. Thus we can identify two (related) strands to the difficulties we face in discussions of world number in EQM. Firstly, world number is sensitive to the coarse-graining of the decoherence basis. A particular coarse-graining of the decoherence basis will deliver a particular enumeration of worlds. Secondly, there is no precise point at which the discretization is too fine-grained or too coarse-grained, and thus no precise demarcation of worlds.

Whilst most proponents acknowledge some unclarity around the number of worlds in EQM, the discussion is often underdeveloped and largely unsatisfying. It seems that whilst there is a coherent response to give those who question the number of worlds in the multiverse, the answer isn't straightforward. Most discussions agree that there is a presumption in the question that isn't compatible with the Everettian framework. Some comments (e.g., Saunders 2010, p.12) suggest that the question, "how many worlds?" has no good answer; counts of worlds are instead "arbitrary conventions" (Saunders 2010, p.313), which are "not well-defined" (Greaves 2004, p.450). Other comments are less sympathetic, suggesting that the question (ultimately) fails to make sense (Wallace 2010, p.68); similarly, it is claimed there is no "physical significance' to the number of worlds, "it is not part of what is really there" (Saunders 2005, p.235). Writing in response to these suggestions, Wilson (2020 p.174) denies that the question is nonsensical but acknowledges that there is "something defective" about it, suggesting world number "is *bivalently indeterminate*: there is some n such that n is the number of worlds, but there is no n such that n is determinately the number of worlds".[45] In chapter 5, I suggest how a more illuminating explanation of indeterminacy must acknowledge the distinction between the *immanent* representation of an Everett world and the *fundamental* representation of an Everett world.

3.7 Quantum Theory and Interference

We have seen how certain assumptions about the (meta)physics of measurement are brought into focus by particular interactions within the classical domain. In some cases, the process of a system gathering information concerning a particular object of knowledge negatively interferes with the outcome of that object of knowledge. In the classical setting, whilst interference effects are specific to particular future-bound objects of knowledge, interference effects in the quantum setting are more widespread. Quantum theory in accordance with those interpretations mentioned above is one that does not support the idea that the process of measurement is one that *reveals* certain *pre-existing* values of a system; we cannot stabilize properties of a quantum system independently of our attempts to ascertain knowledge about that system. On the collapse picture described above, the process of measurement collapses the wavefunction of a quantum system into a new state; the process of measurement does not reveal a certain pre-

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[45] In contrast to the aforementioned authors, Wilson (2020 §5.2) gives more detailed consideration to world number, which I will address in chapter 5.

existing value of the quantum system. We have to be more careful in the Everettian setting. In EQM, different outcomes obtain in multiple branches upon measuring a quantum system; branching is caused by any process which magnifies microscopic superpositions up to a point in which decoherence occurs and the process of measuring a quantum system is one such process.

One might suggest that on the Everettian picture, the process of measurement *does* reveal a pre-existing value of the measured quantum system; if I measure an electron which is in a superposition of spin-up and spin-down states, and I then measure the electron to be in a spin-up state, this spin-up state was (purportedly) a property of the superposition state that has been revealed by the process of measurement. The point here is that the process of measurement has branched the wavefunction. Quantum theory does not permit the process of measurement *to reveal the pre-measurement superposition state*, it does not allow one to effectively stabilize the system as an object of knowledge, and separate the measurer (and measuring apparatus) from the quantum system being measured. The relevance to totality is that trying to stabilize totality (the universe as a whole) in a quantum world requires assumptions that are unjustified according to quantum theory. One cannot effectively stabilize the total state of the world such that our measurement of the system does not interfere with the object of measurement.[46]

John Wheeler's famous variation of the game, *Twenty Questions* may be helpful here.[47] The game in its standard form asks one player, the questioner, to leave the room whilst the rest of the group agree on a particular word. In the knowledge that each member can only answer "yes" or "no", the questioner must guess the word within twenty questions upon her return. In Wheeler's variation of the game, the group does not agree on a word, however; in giving an answer of "yes" or "no", the word in each player's mind must be consistent with her own

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[46] One may object that interference being more widespread in the quantum setting is dependent upon the interpretation of quantum mechanics. It may seem as though those interpretations which give a more central role to the observer in certain collapse pictures or even perhaps QBist approaches (see §4.1) are likely to generate a difference between interference in the classical setting and interference in the quantum setting but more realist pictures (such as spontaneous-collapse theories, for example), one might argue, do not lead to a relevant difference. Even for spontaneous-collapse theories however, I think one is hard pressed to say that the process of measurement is one that *reveals* certain *pre-existing* values of a system in a manner analogous to the classical domain. I concede that this is an area that would warrant further exploration (e.g., what is it for a property of a system to have a *pre-existing* value?) but given the arguments above do not depend on interference being *more* widespread in the quantum setting, I defer a more rigorous treatment of this idea to future research.

[47] It's not obvious that Wheeler has a particular interpretation of quantum theory in mind in this discussion. His analogy forms part of an objection made against (Laplacean) determinism: "…the laws are definite, the initial coordinates and momenta are definite, and therefore the future is definite…that is a cracked paradigm. Quantum mechanics allows us to know a coordinate, or a momentum, but not both. Of the initial value data that Laplace needed, the principle of complementarity or indeterminacy says half do not and cannot exist." (Wheeler 1978, p.8).

answer—and with all answers given before. And so, whilst each player answers the questioner's questions truthfully, no word has been agreed upon in advance. In fact, unbeknownst to the questioner, her questions have at least some role in shaping the outcome; different questions lead to different words.

Comparable to the way the questioner presumed the chosen word existed—using Wheeler's (1978, p.9) phrase—"out there" in the world, the physicist once presumed that measuring the position and momentum of an electron is a process that reveals the status of something that exists independently of the measurement process itself. Quantum theory reveals the scale of interference and in turn reveals that for embedded systems, the stability of the world as an object of knowledge is not supported by the physics. Gathering information about the world in the form of measurement interactions is a process deeply connected in the domain those measurement interactions intend to describe, but the world is such that there isn't something there to be known independently of the questions we put to it. On the Everettian picture, recall the following post measurement state:

a particle is at location ***x*** *and a pointer is orientated left and a sentient observer perceives a measuring device pointer to be orientated left*

+

a particle is at location ***y*** *and a pointer is orientated right and a sentient observer perceives a measuring device pointer to be orientated right*

For an agent gathering information about the world in the form of measurement interactions, one cannot effectively stabilize the world as an object of knowledge and subsequently perform a quantum measurement upon it. Given the measurement process branches the wavefunction, the process is deeply connected to the domain those measurement interactions intend to describe. The world is not something there to be known independently of the measurement process, rather the measurement process is such that particular outcomes obtain as a result.[48]

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[48] I think the overlapping/diverging worlds distinction is relevant here. There is perhaps an intuition which says: the above description is less persuasive on the divergence picture since systems such as agents are world-bound. From the measurement of a quantum system, it's not the case that there is now a difference in pre-measurement world number to post-measurement world number; it's not the case that the measurement has '*split*' the world since quantum systems (such as agents) are world-bound and do not mereologically overlap. This is, I suggest, a little too metaphorical, however. As I explore in chapters 5 and 7, the concepts of branching, world number, and the role of overlapping and diverging worlds in EQM all require a more rigorous treatment in order to illuminate these ideas (and their relation to the concept of totality) most effectively.

Some authors consider these ideas to be salient for one's view of realism. Views such as *QBism*[49] appear to be (for some) the most persuasive route if one takes seriously the idea that the objective world cannot be stabilized as an object of knowledge independently of the measurement process used to describe it. In contrast to the QBists however, I'm sceptical that one needs to revise our notion of the objective world. The issue is not to be explained by a revision of the concept of realism but rather the fact that we are embedded systems in a domain that we are representing, and any attempt to treat the world as a whole will always encounter such effects from the very fact that we are embedded systems in the domain we represent. As I suggest in chapter 4, it is a mistake to interpret interference in quantum theory as a reason to reassess the relationship between scientific (quantum) theories and the world. Before doing so however, I conclude this chapter with a discussion of issues surrounding the distinction between open and closed systems in quantum theory.

3.8 The Open Systems View

A recent proposal due to Cuffaro and Hartmann (2021) is of particular relevance to physical anti-absolutism. Let me first address the relevant technical details and secondly consider some pertinent metaphysical implications.

Writing in response to the well-established orthodoxy of the *closed systems view*, which considers isolated systems to be fundamental, the authors propose the *open systems view*. One way in which physics has made progress is to study subsystems—or "parts"—of the whole universe. In so doing, one partitions a system from its environment and describes the system in terms of the interaction between it (S) and a separate system (E), but when the systems are taken together the result is one isolated compound system. There is however an alternative way to describe a system: one represents the environment's influences by the dynamical equations governing the evolution of the system. On this picture, systems that interact with their environment are considered to be fundamental—this is the *open systems view*.

Despite the physics success stories formulated under the closed systems view[50], there are well-motivated reasons why one may be sceptical. Whilst our best physical theories and

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[49] See chapter 4 for details.

[50] Cuffaro and Hartmann (2021) suggest applications such as atomic physics, nuclear physics and condensed matter physics. Take the case of the hydrogen atom, for example. One can specify the Hamiltonian (although more sophisticated models exist, one can find the Hamiltonian by summing the respective kinetic energy terms for the proton and electron plus a term for the Coulomb attraction of the proton and electron) and then solve the

cosmological models either implicitly or explicitly describe the universe as a closed system, this does not settle the question of whether the universe *is* a closed system. Cuffaro and Hartmann point to two widely discussed challenges.

The first suggests that there is no satisfactory way to define a notion of energy conservation in general relativity (Curiel 2017; Hoefer 2000; Maudlin, Okon & Sudarsky 2020) but one could extend this challenge to quantum theory. Sean Carroll and Jackie Lodman (2021) propose that under the standard textbook (Copenhagen) treatment of measurement in quantum mechanics, energy is not conserved. In Everettian quantum mechanics, they suggest, whilst the expectation value for the energy operator is not constant within individual worlds, it is conserved for the wave function of the universe (including all branches); the energy in the *global* wave function is constant over time. As Maudlin *et al* identify (§3.3.3) however, there are problems inherent within a global perspective, which is the predominant focus of chapter 5.

The second reason stems from the conflict between the unitarity of quantum mechanics and the mixed post-evaporation states of black holes (see Giddings 2013 for a helpful overview). If we are to take the physics of black holes seriously, there is reason to think that the evolution of the cosmos shares more formal similarities with descriptions of open (and not closed) systems.[51]

Cuffaro and Hartmann's (2021, p.3) central concern is quantum theory, identifying two frameworks through which quantum phenomena may be described. The first is *standard quantum theory* (ST), "formulated in accordance with the *closed systems view*" and the second is the *general quantum theory of open systems* (GT), "formulated in accordance with the *open systems view*." Their argument aims to show that GT is more fundamental than ST, both in quantum theory and science more generally. Fundamentality on their view consists of three alternative formulations: ontic; epistemic; explanatory—in all three cases, GT is the more fundamental option.

For Cuffaro and Hartmann, ST and GT are alternative *theoretical frameworks*. The closed system view and open system view are the respective "corresponding *view*(s)" of each theoretical framework, and are distinguished as such:

> On the one hand, ST is formulated in accordance with the *closed systems view*. This is the point of view motivated by the metaphysical position according to which isolated systems are thought of (*a priori*) as making up the subject matter of a given scientific domain, and which is associated with the methodology that models the dynamics of a given open system, *S*, in terms of it being coupled to a

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corresponding Schrödinger equation. The Schrödinger equation describes the behaviour of an isolated or closed quantum system despite widespread entanglement of quantum systems (and thus it often thought that the universe as a whole is the only true closed system).

[51] I discuss this point again in §5.1.

> further system E (representing its environment), such that $S + E$ form an isolated quantum system. GT on the other hand, is formulated in accordance with the *open systems view*. This view is motivated by the metaphysical position according to which the subject matter of a given scientific domain is thought of (*a priori*) to consist, in general, of open systems in interaction with their environment. Its methodology is such that, rather than modeling the dynamics of a given open system S in terms of an interaction between two systems, we instead represent the influence of the environment on S in the dynamical equations that we take to govern its evolution from one moment to the next.

In the way physics has so far proceeded, there are numerous properties one can investigate in which the environment has a negligible influence on the system under investigation.[52] In these instances, physics advances under the assumption that systems are effectively isolated from their environment. Moreover, we can also model physical phenomena in cases where the dynamics of a system are significantly influenced by the system's environment. One considers the open system under inquiry to be part of a larger closed system— one in which both the system and its environment are subsystems.[53] This way of describing and individuating (sub)systems is how physics makes progress on the closed systems view.

In ST, we can use a normalized state vector to represent a quantum system's state. This is not the case in GT. On this view, the physical state of a system is represented by a non-unitarily evolving density matrix. The environment's influence is not described by an interaction between two systems but is incorporated into the representational schema given by the dynamical equations applicable to the evolution of the target system.

On the ST picture, the universe as a whole, namely *totality*, is attributed a privileged ontological status; it is the only true closed physical system. In contrast, the universe on the GT view is a system like any other, obeying the same dynamical laws as its subsystems and bereft of an ontologically privileged status.[54] Moreover, it is suggested that the ontology of the GT picture is clear: the view describes open systems (represented by density operators[55]) as fundamental and the dynamics of these open systems are non-unitary. One quickly runs into metaphysical difficulties in equating totality with an open system but before we attempt to discuss these ideas let us introduce some additional concepts.

Cuffaro and Hartmann (2021, pp.20-21) appeal to the framework set out by Harrigan and Spekkens (2010) to distinguish interpretations of the state vector. An interpretation is said to be $|\psi\rangle$*-ontic* if the state vector describes "the real (observer-independent) state of a physical

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[52] As suggested, the properties of atoms, atomic nuclei or solid-state systems, for example.
[53] The details of this method are given below.
[54] I return to this point in greater detail at the end of this section.
[55] Also known as a *density matrix*.

system". If on the other hand the state vector is taken to describe the system *completely* (thus a one-to-one mapping between the real state of a system and $|\psi\rangle$) we can say the interpretation is also $|\psi\rangle$-*complete*; the quantum state alone is a complete description of reality. A $|\psi\rangle$-*ontic* interpretation is contrasted with a $|\psi\rangle$-*epistemic* interpretation, in which the same real state of a system is compatible with a correct description by more than one quantum state. Given these interpretations do not take the real state to be completely described by $|\psi\rangle$, then $|\psi\rangle$-*epistemic* interpretations are also said to be a $|\psi\rangle$-*incomplete*. Our concern are those interpretations identified as both $|\psi\rangle$-*ontic* and $|\psi\rangle$-*complete*. Those interpretations described as orthodox by the authors (e.g. *neo-Copenhagen*, *QBism*, *pragmatism*, *relational quantum mechanics*) reject the idea that a system has an observer-independent state[56] but however is *complete* in the following sense.[57] Through a particular physical interaction, the description of a system is given by a collection of conditional probability distributions in accordance with unitary dynamics.

Before addressing ST and GT in more detail, I'll introduce some additional mathematical concepts. Recall from §3.3 that when a quantum system becomes entangled with its environment, unitarity is destroyed locally but preserved at the level of the (newly entangled) larger composite system. Presuming there is no collapse of the wavefunction, non-unitarity entails that the maximum information available about one of the entangled subsystems is the complete statistical information about its evolution (in a particular basis), obtained using a *reduced* density matrix.[58]

The state of a system which can be represented by a state vector $|\psi\rangle$ we define as a pure state. If, for example, a system is in a specific state from a particular set—say a pure state $|\psi_i\rangle$ —but we are ignorant which, then such ignorance can be described by a probability distribution over different possibilities. We can represent a state's probability distribution $\{p_j\}$ and the different possibilities $\{\,|\psi_j\rangle\}$ with the following density matrix:

$$\rho \; = \sum_j p_j |\psi_j\rangle\langle\psi_j|$$

This density operator also describes an ensemble of such systems, in which case each element of the ensemble is in a definite state $|\psi_i\rangle$, of which p_j will give the probability (relative frequency)

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[56] See §4.1-4.3 for details.

[57] Of course, the adherents of these views are unlikely to describe their views as orthodox.

[58] Obtained by taking the partial trace of the density matrix.

that elements of the ensemble are in the *j*-th state. Such ensembles that can be given a so-called ignorance interpretation are called *proper* mixtures (d'Espagnat's 1976 terminology).

One can also generate an ensemble by quantum particle correlation: an ensemble of left-hand particles from a set of paired quantum particles is described as an improperly mixed state—in other words, an *improper mixture*. Since (generally) entanglement relations hold between correlated quantum systems, such states cannot be given a probabilistic reading as above, that is, a quantum system from an improperly mixed ensemble cannot be read as being in a state $|\psi_j\rangle$ with a particular probability.[59] On such representations the mixed state arises from considering the description of a subsystem embedded in a larger system, tracing out irrelevant degrees of freedom. The individual systems of an improper mixture cannot be thought of as being in a definite state of which we are ignorant. The (reduced) density matrix in this case is the only appropriate description. For a proper mixture, there is a privileged decomposition, namely the definite states and associated probabilities to which those systems have been mixed. For an improper mixture, there is no sense to the idea of a privileged or "correct" decomposition. The improper mixture is part of a larger (entangled) system.[60] In practice however, there is some subtlety required when distinguishing between the measurement statistics generated from a properly mixed ensemble and an improperly mixed ensemble. This is a point I return to at the end of the section in the context of EQM.

Let us now sketch the relevant details for understanding how open systems are modelled in ST and GT.[61] Cuffaro and Hartmann (2021, p.11-12) consider a closed system (S+E) consisting of a two-state quantum system, S coupled with an environment E. Their assumptions are as follows:

> 1. The total Hamiltonian is given by $H = H_S + H_E + H_{SE}$. Here H_S is the Hamiltonian of the system (i.e. the two-level atom), H_E is the Hamiltonian of the environment which is modeled as an infinite collection of two-level atoms. Finally, H_{SE} accounts for the interaction between the system and the environment.
>
> 2. S+E are initially uncorrelated and weakly coupled, i.e. E affects the state of S but not vice versa. This is sometimes called the *Born approximation*.
>
> 3. The future state of S only depends on its present state. Metaphorically put, S has a short memory and "forgets" its earlier states. This is the *Markov approximation*.

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[59] Entangled states must be considered improper mixtures since an entangled state is one in which there are phase relations among the pure states comprising the ensemble.

[60] The Everettian will disagree about some of the details here, which I will address shortly.

[61] I only include those details which I take to be salient for *physical anti-absolutism*. For those readers who require further details, see Breuer and Petruccione (2007), Carmichael (2013), Davies (1976), Gardiner and Zoller (2004), and Manzano (2020).

The equation representing the evolution of the reduced density operator ρ results from 'tracing out' the variables that represent the environment E. One first evolves S+E forward, and subsequently traces over the degrees of freedom of the environment E; this gives an equation for the reduced dynamics of S in the Lindblad form[62], which generalizes the Schrödinger equation to open quantum systems. By representing the open system as a subsystem in a larger closed system—of which both S+E are subsystems—one accurately describes the (effective) non-unitary dynamics of the system.[63] In GT, recall that the state of a quantum system is not represented by a state vector but rather by a non-unitarily evolving density operator. In contrast to ST in which an open system's dynamics are calculated by taking the partial trace of the *total* dynamics of S+E to the state space of S, the environment's influence on an open system S in GT is represented in the dynamical equations governing the evolution of S.

The state of a system in ST evolves according to the deterministic Schrödinger equation: a system at t_0 represented by the state vector $|\psi(t_0)\rangle$ determines the state of the system at t_1 represented by the state vector $|\psi(t_1)\rangle$. However, for the dynamical evolution of S in GT, there is a natural analogue to this deterministic process in which every dynamical map Λ_t associated with S uniquely maps each state to another state in a specified state space (an example of a *Markov process*)—following from this assumption, one can then mathematically describe a system's dynamics (see Cuffaro and Hartmann 2021, p.14).[64]

In order to derive the Lindblad equation, an open system's evolution must be represented by a "completely positive" and "trace preserving" map. This means that dynamical maps on an open system's state space describes the mapping of one physical state of the system onto another physical state of the system. Moreover, density operators must always be normalized to unit trace since the sum of measurement outcome probabilities must be 1.[65]. Thus, the

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[62] Sometimes called the quantum Liouvillian, Lindbladian or GKSL equation (named after V. Gorini, A. Kossakowski, G. Sudarshan and G. Lindblad).

[63] More formally, the evolution of the reduced density operator is given by the equation (in the quasi-spin formalism): $\dot{\rho} = -i[H_S, \rho] + \mathrm{A}\,([\sigma_-\rho, \sigma_+] + [\sigma_-\rho, \sigma_+])$. The basis states are $|1\,\rangle{:} = (1,0)^T$ and $|1\,\rangle{:} = (0,1)^T$ and the respective raising and lowering operators (sometime called ladder operators) are represented by the Pauli matrices $\sigma_\pm$. The target system decays at a rate represented by A. The dynamics of ρ in this equation have a unitary part—which involves a superoperator (typically an operator that acts on the vector space of other operators) and is given the form: $\mathcal{L}_u\,\rho := -i[H_S, \rho]$—and also a non-unitary part which can be abbreviated by $\mathcal{L}_{n-u}\,\rho$ such that the reduced density operator evolves according to $\dot{\rho} = \mathcal{L}_u + \mathcal{L}_{n-u}\,\rho$, which takes the Lindblad form.

[64] Cuffaro and Hartmann point to other assumptions here; I restrict the discussion to those points which I take to be most relevant to the arguments put forward in the following chapters.

[65] The trace (denoted Tr) of a square matrix is the sum of the elements of the main diagonal. In the case above, $\mathrm{Tr}(\rho) = 1$.

dynamical map on the state space for an open system must therefore be trace-preserving and positive for it to have *physical* significance.

Of particular importance for the physical anti-absolutist, is the notion of *complete* positivity. Let us imagine a system *S*, evolving over time in its environment *E* but in which *S*+*E* are uncorrelated at time t_0. Let us also imagine a further system—following Cuffaro and Hartmann (2021, p.14) we'll call this a "witness" system—W_n, which is inert and non-interacting and where *n* represents the dimensionality of the witness system's state space. We can describe the dynamics of *S* and W_n, by extending the dynamical map Λ_t for *S* on the state space of W_n, by applying the identity transformation I_n, which returns the following map: $\Lambda_t \otimes I_n$. Thus for Λ_t to be completely positive requires firstly that Λ_t should be positive (as outlined above) but also that $\Lambda_t \otimes I_n$ should be positive for all *n*. This however is not the case for *all* Λ_t, in which case such maps aren't valid on *S* if one requires complete positivity.[66] In any case, this seems like a reasonable requirement to make; the validity of Λ_t on *S* should not be affected by the existence of an (inert) system W_n with which *S* isn't interacting.

However, as Shaji and Sudarshan (2005, p.50) suggest, this argument only works when *S* is entangled with W_n. The upshot is that if *S* and W_n are entangled, then "…W_n should really be part of the definition of the environment of *S*", thus a completely positive map only represents the reduced dynamics of *S* if there is no (initial) entanglement between *S* and the environment.[67]

The physical significance of extending a not completely positive map from the state space of *S* to the state space of $S + W_n$ is that some states (in the larger state space comprising $S + W_n$) are mapped to *unphysical* states, namely states which are assigned negative probabilities for particular measurements on $S + W_n$—although, as noted by Cuffaro and Myrvold (2013, §5) such unphysical states are also impossible states.

There is however another way to impose complete positivity (echoed by Raggio and Primas 1982, p.45), which Cuffaro and Hartmann point to. By appealing to *Stinespring's dilation theorem*[68], which says that for a system *S* initially in state ρ we can derive its non-unitary dynamics as a subsystem of a uniquely corresponding—and unitarily evolving—state of larger system of which is represented by a pure state.

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[66] Nielsen & Chuang (2000, p.369) highlight that the *transpose operation* is an example of a positive map which is not completely positive.

[67] See Jordan, Shaji, and Sudarshan (2004, pp. 13-14).

[68] Stinespring 1955.

Complete positivity (from Stinespring dilation) is what ensures one can derive a dynamical equation for an open system by a contraction of a larger closed system (*S*+*E*). This is reasonable for completely positive maps, but the contraction to a not completely positive map, as noted by Sudarshan and Shaji (2003, p.5080), "have to be viewed as contractions of the evolution of unphysical systems". For the closed systems view, in which the dynamics of an open system *S* are accounted for by the evolution of the closed system *S*+*E*, this is a problem. As Cuffaro and Hartmann (2021, p.17) put it:

> This is problematic on the closed systems view, for which the evolution of an open system *S* is always described in terms of the evolution of a larger closed system *S*+*E*. On the closed systems view, a not completely positive map on S's state space makes no physical sense, though one might perhaps permit its use as long as one understands that it is merely a mathematical tool that does not describe the dynamics of an open system in a fundamental sense. On the open systems view, by contrast, it is not really surprising, and in any case not at all problematic, that the larger closed system from which we may (if we find it convenient to do so) derive a not completely positive map on the state space of *S* via a contraction is unphysical. It is neither surprising nor problematic because the methodology of the open systems view does not require that we model an open system as a subsystem of a closed system. On the open systems view there is no need to conceive of the dynamics of an open system as a contraction of anything.

The crux of this idea, and our main concern here is that this is true even if we conceive of *S* as the whole universe. For orthodox interpretations of ST, one introduces a hypothetical transcendental system to interact with the universe as a whole—the *closed* system (*S*+*E*) is an abstract formulation, "it encodes the abstract possibility space of the system in the context of an interaction with an external environment" (Cuffaro and Hartmann 2021, p.24). It is a framework that entails one to simulate extra degrees of freedom that enable one to represent a system's dynamics, despite whether such extra degrees of freedom bear any *physical* significance.[69]

Let us now consider the Everett interpretation under Cuffaro and Hartmann's *open systems view*. It will first be useful to revisit the notion of proper and improper mixtures on the assumption of EQM. Recall, the distinguishing feature amongst these two types of mixed state was *ignorance*: the density operator representing a system which is in a specific (or definite) state from a particular set—say a pure state $|\psi_i\rangle$ —but we are ignorant which, is described as a *proper*

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[69] Bohr (1958, pp.392-393, emphasis added) comparably suggests: "In the treatment of atomic problems, actual calculations are most conveniently carried out with the help of a Schrödinger state function, from which the statistical laws governing observations obtainable under specified conditions can be deduced by definite mathematical operations. It must be recognized, however, that *we are here dealing with a purely symbolic procedure, the unambiguous physical interpretation of which in the last resort requires a reference to a complete experimental arrangement.* Disregard of this point has sometimes led to confusion, and in particular the use of phrases like 'disturbance of phenomena by observation' or 'creation of physical attributes of objects by measurements' is hardly compatible with common language and practical definition."

mixture. An ignorance interpretation does not apply to those density operators which arise from tracing over the degrees of freedom from a system's interaction with another (entangled) system since one is not ignorant of a definite state. Such states are *improper* mixtures.

Following Wallace (2012 §10.4), the peculiarity can be put another way. There are (orthodox) interpretations of quantum theory in which declaring a system is in a proper mixture is an epistemic statement about my (limited) knowledge of a system, whilst declaring a system is in an improper mixture is an ontic statement—a statement about the system itself. This peculiarity is severely weakened on the Everettian approach however, since Everettians give a reasonably straightforward response to the idea that improper mixtures define a system which cannot be understood as being in a definite state of which we are ignorant. Consider the entangled (pure) state again:

$$|\psi\rangle=\frac{1}{\sqrt{2}}(|\uparrow|\downarrow\rangle+|\downarrow|\uparrow\rangle)$$

And now suppose that the first particle is moved to a distant location, tracing out all degrees of freedom associated with the second particle and representing all possible observables for the first particle with a *reduced* density matrix. On the Everettian picture, the particle is in a definite state but since the particle is entangled (with the second particle), knowing the definite state of each particle is not sufficient to describe the joint state of both. If we now suppose an agent measures the particle spin, the state of the particle does not change but what does change is the particle becomes entangled with the measuring instrument and its environment. More formally, the evolution can be described as follows, with 'ready', 'up' and 'down' representing the states of the measuring device plus agent plus environment as, respectively, no measurement, up-measurement and down measurement:

Particle evolution: $\frac{1}{2}(|\uparrow\rangle\langle\uparrow|+|\downarrow\rangle\langle\downarrow|)\longrightarrow\frac{1}{2}(|\uparrow\rangle\langle\uparrow|+|\downarrow\rangle\langle\downarrow|)$

Particle plus measuring device plus environment evolution:

$$\frac{1}{2}(|\uparrow\rangle\langle\uparrow|+|\downarrow\rangle\langle\downarrow|)\otimes|\text{‘ready’}\rangle\langle\text{‘ready’}|\longrightarrow$$
$$\frac{1}{2}(|\uparrow\rangle\langle\uparrow|\otimes|\text{‘up’}\rangle\langle\text{‘up’}|+|\downarrow\rangle\langle\downarrow|\otimes|\text{‘down’}\rangle\langle\text{‘down’}|)$$

And so from a *transcendental* perspective, there is no difference locally between an improper and proper mixture. That which distinguishes the two mixtures is the entanglement with its environment. One may subsequently suggest that there is little motivation to retain the category of proper mixtures since complete theories which propose mixed states *always* result from tracing out unwanted degrees of freedom; in virtue of what should the classification of mixed states as *proper* mixtures be upheld on the Everett picture? In a nutshell: there is a useful distinction if the state is relativized to an agent's branch.

Consider again the setup above. Prior to measurement, the state of the particle is represented thus:

$$\frac{1}{2}(|\uparrow\rangle\langle\uparrow|+|\downarrow\rangle\langle\downarrow|)$$

But after the measurement, the state *relative to the agent* will be either $|\uparrow\rangle\langle\uparrow|$ *or* $|\downarrow\rangle\langle\downarrow|$ but the agent (given she hasn't yet looked at the result) does not know which.[70] That is, the state of the particle is in an improper mixture but relative to an agent who is yet to observe the measurement outcome, the particle is in a proper mixture, namely there is some fact which describes the state the system is in (and of which she is ignorant). If it is cogent to assign a fact to multiple branches of the wavefunction, an agent who declares a system to be in a proper mixture then can be understood as giving an ontic statement about the system that comprises multiple branches (as Wallace 2012 pp.395-6 seems to), rather than a statement expressing her epistemic state concerning the system. The physical and conceptual status of objects (and their states) which purportedly span multiple branches will be assessed in chapter 5. At first glance however, if one is worried about systems being constituted by entities in multiple branches, then it looks like the notion of a proper mixture is only valid on the Everett picture if we appeal to relative or indexical facts.

Thus within the framework of ST, the Everettian ontologically commits to both open systems (in which the degrees of freedom of a system are coupled with those of its environment) and closed systems (the universal state vector). As we will see, the state vector represented as a density operator is valid in the frameworks of ST and GT, whilst the state vector $|\psi\rangle$ is applicable only to ST.

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[70] Despite adopting the term 'relative' here, the discussion above still assumes multiple emergent worlds consistent with contemporary decoherence based EQM, and is not to be confused with Everett's relative state formulation.

Recall the ontology of GT is that of open systems; systems that (in general) interact with an external environment, represented as non-unitarily evolving density operators. GT differs from ST in that it removes the aforementioned transcendental observer of ST, the hypothetical second system introduced to describe the dynamics of the open system in question. Let us now consider the universe as a whole on the open systems view.

As previously noted, the authors point to a tension between the metaphysical position that motivates a particular framework to be formalized in terms of certain objects and the ontology revealed by those objects when taken seriously. In ST for example, we saw how the metaphysical position which suggests that a quantum system—represented by a state vector—is not consistent with the way those systems are represented; the framework of ST is situated within the *closed systems view* yet the systems it describes are in practice almost always open[71] (and in the case of the authors' orthodox interpretations, *exclusively* open). The *open systems view* is the corresponding view of the GT framework, which represents systems as (generally) open—closed systems do exist within GT, the framework simply rejects the idea that *only* closed systems exist.

The cosmos, or totality, is a closed system in GT and is our main concern here. In ST, closed systems evolve unitarily. In GT however, the dynamics of a closed system—and therefore the cosmos—allow for non-unitary evolution. As Cuffaro and Hartmann (2021 §5.3) suggest, there are difficulties in interpreting the non-unitarily evolving cosmos as either an open or closed system. If we model the cosmos as a closed system, we require extra terms beyond those that correspond to the system's Hamiltonian, terms which describe the system's interaction with its environment—clearly a problem if the system is already defined as a totality. If on the other hand we interpret the cosmos as an open system then we're confronted with an equivalent problem; a system's environment is central to the description of an open system, but in what does this environment consist if totality has already been specified? Cuffaro and Hartmann (2021, p.46) suggest "that the ontological distinction between open and closed systems (at least when it pertains to the cosmos) breaks down in GT." The lesson, they suggest, is a reminder that not every mathematical concept (e.g., density operators, state vectors) in our ontological investigation will line up with those pre-theoretic concepts we have about the universe.

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[71] Although I do not support the view here, the standard line is to say except in quantum cosmology, for example, when describing the universe as a whole.

One answer to the question of what it means to describe the entire universe as a non-unitarily evolving density operator is simply that the form it takes is just a brute fact. Cuffaro and Hartmann (2021, p.47) suggest:

> An alternative…is to think of the form taken by the dynamical evolution of the cosmos as just a brute fact, which we can describe in GT, but which, like the principle of inertia in Newtonian Mechanics, is not subject to further explanation. But just like the brute fact of the principle of inertia in Newtonian Mechanics, the brute fact of the form of the dynamics of the universe is one that may potentially lead the way to new physics. Could this new physics lead us back to a kind of closed systems view in the end? We think this is unlikely, and anyways it would require a re-conceptualization of what a "closed system" is.

Whilst it's difficult to refute such a possibility, a more fruitful and more promising solution, I suggest, is that the cosmos does not admit of a total description. I think the notion of the universe as a whole is a deep, difficult idea that deserves rigorous attention, and both the communities of philosophy and physics should be open to exploring more radical metaphysical pictures that may (at least) help sharpen concepts—such as open and closed systems—that are often employed in this setting.

This chapter has suggested reasons to be sceptical of an all-inclusive physical domain. In logic, metaphysics and now in physics I have proposed that there are reasons to doubt the coherence of an absolutely general physical domain. In chapter 4, I consider these ideas in the context of quantum theory and objectivity, which will setup the case study of Everettian quantum mechanics in chapter 5.

4. Quantum Mechanics and Objectivity

This chapter explores how we should think about the idea of an objective world in view of the fact that the world is quantum mechanical, and how we should think about the idea of an objective world in consideration of the previous discussion of totality and physics.

Discussion concerning the status of an observer-independent reality is typically situated within the debate between *realist* and *antirealist* views; for the purposes of this chapter, I'll consider the *realist* and *antirealist* views of quantum theory. The standard story of quantum mechanics often cites antirealists (sometimes *operationalists* or *instrumentalists*) such as Bohr, Heisenberg and Dirac who purportedly abandon aspirations to provide a description of an observer-independent reality and instead offer an algorithm for predicting the results of quantum measurements[1]. Realists on the other hand (often associated with the views of Everett, Bohm and Bell) suggest that theoretical claims refer to knowledge about the world, namely descriptions of a mind-independent reality. Glossing the debate in this (dichotomous) way is a little contentious: the writings of some antirealists such as Bohr make it explicit that the wavefunction is not merely a calculational tool for predicting measurement results and whilst Everettians may appeal to the thought that EQM "is really just quantum mechanics itself understood in a conventionally realist fashion" (Wallace 2013, p.461), the notion of realism here (at least according to some) is not entirely transparent (see Halvorson 2019).

My aim here is not to defend either the realist or antirealist position but rather to consider the debate in view of the previous discussion of totality. The domain of applicability for both realist and antirealist views is reality considered as a totality; since much of the realism-antirealism debate is, I think, sensitive to ideas about totality, and extant discussion does not explore the problems inherent in attempts to stabilize totality as an object of knowledge, I propose that these ideas should bear significant weight in defence of either position.

4.1 QBism

To begin, let us address the motivation for thinking that the quantum state is not a *description or representation of physical reality*. It appears one reason for denying a link between the quantum state

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[1] See e.g., Ney and Albert 2013, pp.14-15.

and the description or representation of physical reality is the central role assigned to notions such as 'observer' and 'measurement' in quantum theory—a point famously argued by John Bell (1990, p.34):

> What exactly qualifies some physical systems to play the role of 'measurer'? Was the wavefunction of the world waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer, for some better qualified system…with a PhD?

Chris Fuchs (2010) has recently argued that the overarching strategy in quantum foundations has since been to find ways to either remove these notions ('observer'; 'measurement'), or at the very least account for their significance in purely physical terms. For example, the de Broglie-Bohm 'pilot-wave' theory says that the positions of particles are the so-called 'hidden variables'; in contrast to rival theories, the wavefunction does not describe or represent a quantum system but instead guides the motion of particle positions. By rendering the wavefunction incomplete, the theory attributes measurements no special status—the values of the variables that register the experimental outcome are included in the description. Similarly, 'spontaneous-collapse' models remove the process of measurement by introducing stochastic and spontaneous localization of particles around particular positions; and as discussed in chapter 3, all outcomes obtain post-measurement for the Everettian. In each case, we see a strategy to incorporate notions such as observer and measurement into the theory in a way that attempts to dissolve the distinction, highlighted by Bell, between measuring and non-measuring systems.

Fuchs (2010, p.2) proposes that these strategies are "quick fixes", which are "interpretive strategies hardly compelled by the particular details of the quantum formalism". One point that the founders of quantum theory (attributed to Heisenberg, Pauli, Einstein) and the young cohort of the Copenhagen school (attributed to Peierls, Wheeler, Peres) were unified upon, he suggests, was "that quantum states are not something out there, in the external world, but instead are expressions of information…the world may be full of stuff and things of all kinds, but among all the stuff and all the things, there is no unique, observer-independent, *quantum-state kind of stuff*." (Original emphasis).

Recall one can use the Born rule to generate probabilities for the measurement of a quantum system to deliver a particular result. For Fuchs, and all those that endorse *QBism*[2], such probabilities are *subjective* degrees of belief: quantum probabilities map on to the future of

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[2] Although Fuchs would strongly disagree (see Fuchs 2017), QBism may be seen as something like a 21st century manifestation of antirealism.

an agent's experience (upon measuring a quantum system) rather than probabilities that tell us about the quantum system itself.[3] Quantum states are "like personalist, Bayesian probabilities" (Fuchs 2010, p.5); they encode the subjective belief of an agent with a particular quantum system.[4] The payoff of this strategy, we are told, is that it erodes many of the difficulties found in those interpretations that objectify the quantum state; if states are understood epistemically, such states exhibit many characteristics of quantum information. A notable example of this, acknowledged by Fuchs (2010, p.3), is that given by Robert Spekkens (2007).

Spekkens offers a simple (classical) toy theory that restricts the amount of knowledge an observer has about reality such that the number of answered questions concerning the physical state of a system must always be equal to the number of unanswered questions (in a state of maximal knowledge). Setting up the model according to this information-theoretic principle manages to reproduce a number of quantum phenomena (e.g., no-cloning theorem, entanglement monogamy, interference in a Mach-Zender interferometer). Whilst the model cannot account for all quantum phenomena, there are features (e.g., no-cloning theorem) which in contrast to the ontic view, arise naturally on the epistemic view of quantum states. By rejecting the standard realist assumption that proposes a relation between the interpretation of quantum theory and the description of external reality, the epistemic view (perhaps more modestly) renounces the so called 'God's-eye view', and instead only refers to the multiple *subjective* degrees of belief associated with each agent's future experience.

The relationship between a view such as QBism and scientific realism is a strange one. It seems that despite rejecting the idea that the quantum state is a state that offers a description or representation of 'external reality', the QBist does not view the theory as any less *realist*. The QBist does not deny the existence of an external reality but rather rejects that the quantum state describes it. It aims to respond to science's misconceived (according to the QBist) preoccupation with an external reality that is described without the introduction of subjects. In

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[3] If the Born rule is a way to generate probabilities (for an observable taking a particular value) from the quantum state, does the QBist not endorse—contrary to their central claim—an objective quantum state? This worry is addressed by the QBist's reformulation of the Born rule given in DeBrota et al. 2020.

[4] Comparably, *pragmatist* views about quantum theory (e.g., Healey 2012; 2017; 2020) agree that the ascription of a quantum state is not a description of physical reality; quantum theory does not describe or represent physical reality, but they see no reason why quantum probabilities should be *subjective* degrees of belief. Rather, for pragmatists, quantum theory is *objective*, not because the theory is a description or representation of the physical world, but because there is a widely shared agreement and norm within the scientific community, which derives from "the scientific aims of prediction, control and explanation of natural phenomena" (Healey 2012, p.736). If multiple (different) agents assign different quantum states to the same system, these are not representations of each subject's belief but are objective probabilistic relations—each agent has access to different objective information. Healey prioritizes *use* over *representation*; in view of the preceding chapter, I would suggest that this distinction isn't as precise as the pragmatist tradition has assumed. (See §4.4 for details).

Mermin's (2016, p.5) words, "scientific pictures of the world rest on the private experiences of individual scientists", and "each of us has a view of the world that rests entirely on our private personal experience". One way this is brought to bear is through the QBist's reformulation of the Born rule. Given the Born rule (as is typically construed) postulates a relationship between the probability of a given quantum mechanical measurement result and the (squared-)amplitude of the component of the state associated with that result, there is reason to reject such a description on the QBist view since implicit in this formulation is a quantum state that *describes external reality*.

The QBists offer an alternative picture: the probabilities assigned to experimental outcomes are to be understood in terms of the probabilities assigned to the outcomes of other experiments (for details see DeBrota *et al.* 2020). In this guise, the rule "doesn't set or fix the values of the probabilities—those depend upon the agent's prior personal experiences, his computational powers, and a good amount of guesswork—but the equation itself is something he should *strive* to satisfy with his gambling commitments (i.e., probability assignments)." (Fuchs 2017, p.6). As such, Fuchs suggests, the Born rule "lives in what Einstein calls the "objective factor"…And…correlates with something that one might want to call "real"."[5] Along similar lines, we are also told (Fuchs 2010) that the dimension of a Hilbert space associated with a physical system may also claim to be an objective feature of reality.

It seems that despite attempts to forge a link with scientific realism, with such minimal commitments, QBists must still reject a large swathe of the realist picture. By their own admission, "quantum mechanics itself does not deal directly with the objective world; it deals with the experiences of that objective world that belong to whatever particular agent is making use of the quantum theory". (Fuchs *et al.* 2014, p.3). What is the nature of the external world on such a view? It seems one requires more than advocating the objectivity of the Born rule in order to constrain the metaphysics—as it stands, the fundamental level of physical reality is, in Timpson's (2008) words, "unspeakable"; the external world is "ineffable" (Brown 2019).[6]

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[5] As Glick (2021) suggests, although Fuchs highlights a comparison with structural realism, without further exposition, it's difficult to see what Fuchs really means here.

[6] It's not entirely clear what ineffability amounts to in this context, however Brown's analogy with Berkeleyan idealism is perhaps our best insight. Berkeley (1710) suggested that there was no advantage to the postulation of matter, since the action of matter on mind is inexplicable with or without the supposition of matter. Comparatively, argues Brown (2019), quantum mechanics for the QBist *models* physical systems such as atoms or other agents; it specifies quantum states (and dynamical behaviour), which are best understood as "beliefs" belonging to a single agent. After all, quantum mechanics under the QBist view "does not deal directly with the objective world; it deals with the experiences of that objective world that belong to whatever particular agent is making use of the quantum theory" (Fuchs *et al.* 2014, p.3).

A defining feature for the QBist, as I understand it, is the stimulus and response between the agent and the world—it is this which shapes the metaphysics of an external reality. Mermin (2016, p.8) for example, suggests "science is about the interface between the experience of any particular person and the subset of the world that is external to that particular user." Fuchs and Schack (2004, p.185) put the point like this:

> In fact, one might go further and say of quantum theory, that in those cases where it is not just Bayesian probability theory full stop, it is a theory of stimulation and response. The agent, through the process of quantum measurement stimulates the world external to himself. The world, in return, stimulates a response in the agent that is quantified by a change in his beliefs—i.e., by a change from a prior to a posterior quantum state. Somewhere in the structure of those belief changes lies quantum theory's most direct statement about what we believe of the world as it is without agents.

Elsewhere this notion motivates Fuchs' reasoning for (a version of) metaphysical realism: "we believe in a world external to ourselves precisely because we find ourselves getting unpredictable kicks (from the world) all the time." (Fuchs 2017, p.8). In Healey's (2022, §2.2) words (writing on Fuchs), "as agents using quantum theory to make wise decisions we are not just placing bets on an unknown but timelessly existing future but actively *creating* that future reality". (Original emphasis).

The notion that Fuchs points to is strongly reminiscent of the notion of interference discussed in chapter 4. What I hope to suggest here is that whilst it's true that agents receive seemingly "unpredictable kicks" (from the world), this is not, *pace* Fuchs, a feature that should motivate a view that quantum states do not describe or represent an external reality. This stimulus-response feature which Fuchs acknowledges is, I propose, interference, as described in chapter 4, and is not a feature specific to the quantum domain. It's a result that arises when an embedded system cannot stabilize certain facts or features of the world as objects of knowledge.

Elsewhere, Fuchs (2010, p.8) gives another insight into the nature of this feature:

> QBism says when an agent reaches out and touches a quantum system—when he performs a *quantum measurement*—that process gives rise to a birth in a nearly literal sense. With the action of the agent upon the system, the no-go theorems of Bell and Kochen-Specker assert that something new comes into the world that wasn't there previously: It is the "outcome", the unpredictable consequence for the very agent who took the action. John Archibald Wheeler said it this way, and we follow suit, "Each elementary quantum phenomenon is an elementary act of 'fact creation'."

And again, in Fuchs (2017, p.9):

> When an experimentalist reaches out and touches a quantum system—the process usually called quantum 'measurement'—that process gives rise to a birth. It gives rise to a little act of creation. And it is how those births or acts of creation impact the agent's expectations for other such births that is the subject matter of quantum theory.

A description of quantum phenomena in this way must, I think, acknowledge the notion of interference. For an embedded subsystem of a particular environment, there are situations in which objects of knowledge about particular systems cannot be stabilized independently of ascertaining knowledge about those systems. We see a similar feature in Wheeler's version of twenty questions; no word is agreed upon in advance—the questioner's questions have the capacity to shape the outcome (different questions lead to different words). And so whilst it may be true (albeit rather colourfully) that the quantum measurement process "gives rise to a birth in a nearly literal sense" or that "each elementary quantum phenomenon is an elementary act of fact creation", these creations aren't necessarily central to the "subject matter of quantum theory" as the QBists propose, but are a feature of both quantum and classical systems, and can be explained by the fact that knowledge of quantum systems is not something that can be stabilized independently of ascertaining knowledge about those systems.

For QBists, the process of "fact creation" motivates a view to reconsider the representational or descriptive role of the quantum state in favour of the subject (agent) associated with a particular physical system. In fact, Fuchs (2017, p.1) says that QBism and associated views "should be regarded as attempts to make a deep statement about the nature of reality". But for all those who endorse those ideas set out in chapter 4, there is a far more deflationary, far more modest reading of the "unpredictable kicks" that Fuchs identifies, a reading which says that this type of behaviour is just what happens when a system is embedded within an environment it attempts to model. If this feature is acknowledged from the outset and is recognised as a phenomenon that is present in the classical setting but is more pervasive in the quantum setting, there is less motivation towards a view which makes claims about an external reality with such little contact with more orthodox realist views.

It's contested to what degree the QBist view is consistent with scientific realist claims. Even the more sympathetic readings of QBism suggest that "almost nothing in the model corresponds to an element of reality" (Glick 2021, p.8) but the nature of this debate, I propose, has failed to acknowledge the notion of interference, which I consider to be crucial to any consideration of realist or antirealist views. It appears the notion of interference in quantum theory has led some authors (e.g., Fuchs) to reassess the relationship between scientific (quantum) theories and the world. As such, for Fuchs and all those who endorse QBism (and related views), quantum theory gives motivation to reconsider orthodox realist views. However, I don't see why the quantum phenomenon highlighted by the QBists must motivate a reconsideration of our understanding of the external world or "make a deep statement about the nature of reality" when more robust, more general[7] explanations of the sort described above are available. The fact that we have an explanation of the phenomenon Fuchs identifies in the classical setting goes some way to show how such phenomenon should not motivate a view which attempts to modify the foundations of quantum theory—particularly at the cost of incorporating a view of external reality which many critics describe as *ineffable*.

The debate about (anti)realism generally omits discussion of the phenomenon of interference—to its disadvantage. If lessons from the metaphysics of totality draw attention to features of reality that are central to motivate notable views which attempt "to make a deep statement about the nature of reality", these lessons should be recognised in debates about (anti)realism and discussed in detail.

4.2 A Direct Representation of Reality

In the previous section, I suggested that those who endorse QBism (and related views) have mistakenly taken a particular feature of reality—a feature pertinent to situations in which objects of knowledge about particular systems cannot be stabilized independently of ascertaining knowledge about those systems—to motivate a view that reconsiders the descriptive or representational status of the quantum state. In doing so, QBists are by their own lights adopting a position that makes little contact with orthodox realist views about the nature of an external world. Such accounts sit within a class of views sometimes called *selective scientific realism*[8], a term intended to capture the fact that whilst our best physical theories tell us about the world, they do so by carefully distinguishing those elements of the theoretical model which are genuine elements of reality from those which are representational artefacts. If, however, one is sympathetic to the type of view offered by Rayo (2019, 2022) above, there may be reasons to think that disentangling genuine elements of reality from the representational artefacts of the theoretical model may be a more challenging task than has been previously thought. If we take seriously the idea that there isn't a particular ontology that is singled out independently of the methods used to represent the world, this has important implications for questions of realism about quantum theory.

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[7] Generalized in the sense that interference is present in both classical and quantum settings.

[8] Whether QBism can be categorized as a selective scientific realist view is an open question (see e.g., Glick 2017) but this does not detract from the QBist's claim that their view is realist; Fuchs (2017) chosen term is "participatory realism".

A particular feature central to standard scientific realist accounts is the correspondence between the theoretical model and a perspective-independent description of the world. For example, in a special relativistic setting, the variant perspectival properties are generally understood to be grounded by invariant properties used to describe a more fundamental reality.[9] The 'incompatible' facts one may assign to events (for example, special relativistic cases in which two observers acknowledge an event happening at different times) are judged to be no more than *appearance.* On standard accounts, they are perspectival representations of a non-perspectival world. Similarly, quantum models are typically taken to describe a 'God's-eye description' of the world.

In addition to the QBist picture, there are views (e.g., Dieks's 2022 perspectivalism; Rovelli's 1996, 1997 relational quantum mechanics) which reject the idea that quantum models describe the world according to a God's-eye—or equivalent—view. Quantum theory concerns the role of agents' perspectives rather than a single God's-eye view (expressed using quantum states) for a given system.[10] What is the nature of the God's-eye description that such views reject? In our context here, it seems fruitful to explore the distinction between a God's-eye description in which there *is* sense to be made of an all-inclusive physical domain and a God's-eye description in which there is *no* sense to be made of an all-inclusive physical domain.

Intuitively one might presume that the type of God's-eye description authors reject is one that describes a complete *total*. But what are the implications if a God's-eye view is a view of a physical domain which is incomplete? In order to answer this question, let us briefly consider those views which purport to be explicitly realist about quantum theory, granting "ontological status" to the quantum state.

There appears to be at least some reason to think that the scientific realist should be committed to some form of *literalism* in the following sense. Writing nearly fifty years ago, Van Fraassen suggests that "the aim of science is to give us a *literally true story of what the world is like*; and the proper form of acceptance of a theory is to believe that it is true." (Van Fraassen, 1976, original emphasis). The association is echoed more recently by Chakravartty (2017) who writes:

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[9] See Lipman (2018) for an insightful approach in response to this idea.

[10] There is a notable contrast with QBism here. For Rovelli and Dieks, quantum theory concerns the relational properties between physical systems rather than the intrinsic properties of physical systems, rejecting a single "God's-eye" quantum state and replacing it with a plurality of quantum states that are defined relative to the relevant physical systems. To make sense of quantum theory, such views attempt to give a description of an external reality by appealing to the theoretical elements of the quantum model. QBism, on the other hand, simply rejects the idea that quantum theory should provide a description of an external reality by appealing to the theoretical elements of quantum theory. Instead, quantum theory is a model that applies only at the level of agents operating in the world.

"Semantically, realism is committed to a *literal* interpretation of scientific claims about the world" (emphasis added). This tradition is also present amongst foundational discussion in quantum theory. According to Wallace and Timpson (2010, p.703) for example, "Traditionally realist interpretations…read the quantum state *literally*, as itself standing *directly* for a part of the ontology of the theory" (emphasis added). In doing so, there appears to be some suggestion that there is a close connection between reading the quantum state literally and the claim that the quantum state is a *direct* representation of reality—a theme reiterated in Carroll (2017, p.167): "The simplest possibility is that the quantum wave function isn't a bookkeeping device at all…the wave function simply represents reality directly."

What does it mean for a representation to represent reality directly? I follow Halvorson's (2019) criteria here for assessing what it could mean for the wavefunction to represent reality directly. There are three salient options to consider:

1. "Y directly represents X just in case every property of Y is also a property of X."

2. "Y directly represents X just in case every mathematical property of Y corresponds to some physical property of X."

3. "Y directly represents X just in case Y and X are isomorphic."

Option 1 is logically consistent but the implications of this criteria generate a view which I suspect the above authors will find difficult to accept. Given X has the property of being identical to X, and that Y directly represents X just in case every property of Y is also a property of X, then $Y = X$. It then follows that the universe is just the type of entity that the wavefunction is. If, as I think most would accept, the wavefunction is an abstract mathematical object then the universe is an abstract mathematical object. The implications of this result are severe; if this result is what the above authors intend when claiming that the wavefunction represents reality directly, it would be remiss not to state this explicitly—let us therefore assume this is not the view endorsed.[11]

Option 2 attempts to alleviate the result of option 1 by posing a correspondence rule between mathematical properties and physical properties. Halvorson's (2019, p.146) line is that

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[11] Contemporary "Pythagoreans", notably Tegmark (2008) argue that the physical world is an abstract mathematical structure, but this is a minority view.

we need "some precise account of the "mathematical properties" of *Y*", suggesting that if we employ standard set-theoretic practice, mathematical properties of *Y* will be represented using the Zermelo-Fraenkel (ZF) set theoretic language. Despite two wavefunctions having the same form (Halvorson 2019 pp.146-147 suggests a form characterized by features such as: both wavefunctions being represented by standardized Gaussian distribution, and that the "wavefunctions are written in the configuration space basis, and with the origin representing the same point in the universe") wavefunctions can be distinguished by properties such as the empty set being an element of the domain of the wavefunction. Thus if option 2 is true, that is, "if *Y* directly represents *X* just in case every mathematical property of *Y* corresponds to some physical property of *X*", two wavefunctions may be distinguished solely by whether or not one believes that the empty set corresponds to a physical property. Again however, this is a strange result; it's not clear why one should attribute physical properties to fine-grained set-theoretic features that have no obvious physical correlate in the theory. If two wavefunctions are described by the same equation; represented by a standardized Gaussian distribution; written in the configuration basis and share a particular point in the universe as their origin, there is little reason to think that such wavefunctions aren't identical.

Moreover, it's not obvious that physical reality is such that its physical properties are structured in such a way that permits unique correspondence with the mathematical properties of a representation, as suggested by option 2. To be more specific, some authors may cite the so-called *problem of metaphysical underdetermination*. Paraphrasing James Ladyman's (1998 pp.419-420) well-known passage advocating structural realism, if one adopts a metaphysics of objecthood then one encounters the problem that one's putative objects' "individuality profile" (as Brading and Skiles 2012 put it) is underdetermined by the physics; entities such as electrons can be interpreted as either individuals or as non-individuals and as such it is a failure of our best theories that one of the most fundamental ontological characteristics is metaphysically underdetermined. To believe in entities which have such an equivocal metaphysical status, Ladyman charges, is an *ersatz* form of realism. It's not enough for the scientific realist to propose that there are in fact electrons, the scientific realist owes an account of what electrons actually (metaphysically) are, and if the physics can't provide such characteristics, it's perhaps worth seeking a different ontological basis altogether.

Carrying over to our discussion here, if the nature of the system being (directly) represented is undermined by the physics, that is, if the physical properties of *X* are metaphysically underdetermined, it's not immediately clear how to assign corresponding mathematical properties in *Y*. In other words, it's difficult to understand how "*Y* can directly represent *X* just in case every mathematical property of *Y* corresponds to some physical property of *X*" if one cannot give an account of the physical properties of *X*—in this case, how particular entities are individuated.

Let us now consider the implications for the view of option 2 in view of physical anti-absolutism. Can the wavefunction directly represent reality if reality is incomplete?[12] If there is substance to the idea that there is no sense to be made of an absolutely general *physical* domain, and we accept option 2, it's not clear how the wavefunction can directly represent reality if reality cannot be stabilized as an object of knowledge. Recall in §3.7, I suggested that quantum theory does not support the idea that the process of measurement is one that *reveals* certain *pre-existing* values of a system; we cannot stabilize properties of a quantum system independently of our attempts to ascertain knowledge about that system. Given we understand reality to be at some level quantum mechanical, then trying to stabilize totality, namely the universe as a whole, requires assumptions that quantum theory does not endorse. Implicit in the criteria of option 2 is that there is a particular system with particular physical properties, a system which can be stabilized as an object of knowledge that we call *X*, a system whose properties can be stabilized such that one can find the corresponding mathematical properties in *Y*. As suggested in chapters 3 and 4 however, there are some properties such that, for any class of terms all having such a property, one can always define a new term that has the property in question—in attempting to define a collection of terms, the collection itself generates a new term which has that property. Thus for any embedded system, there simply isn't a fact available that can fix the total state of the world, a fact which specifies that *that is everything*, and in virtue of this absence, there isn't something there to be known as an object of knowledge, there isn't something there to be known as a particular, metaphysically privileged, object of knowledge that one can *directly* represent with abstract mathematical objects.

There is one further reason to be sceptical of an account that proposes a correspondence between mathematical properties of *Y* and physical properties of *X*. Recall Cuffaro and Hartmann's suggestion that the ontology of GT is that of open systems; systems that (in general) interact with an external environment, represented as non-unitarily evolving density operators. Recall further that there are problems in interpreting the non-unitarily evolving cosmos as either an open or closed system (§3.8). If we model the cosmos as a closed system, we require

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[12] One may find it helpful to distinguish between incompleteness and incompletability. Incompleteness is no problem: we can represent incomplete objects with incomplete representations. Rather, the question refers to how the wavefunction can represent reality if reality is incompletable—namely, that there is no sense to be made of a complete, absolutely general physical domain.

terms in addition to those associated with the Hamiltonian of the system, which are typically attributed to the interaction between the system and its environment. This is clearly a problem if the system is already defined as a totality. If on the other hand we interpret the cosmos as an open system then we're confronted with an equivalent problem: a system's environment is central to the description of an open system, but in what does this environment consist if totality has already been specified? Recall Cuffaro and Hartmann's (2021, p.46) conclusion that "the ontological distinction between open and closed systems breaks down" when describing the universe as a whole, suggesting that not every mathematical concept (e.g., density operators, state vectors) in our ontological investigation will line up with those pre-theoretic concepts we have about the universe. I take it that all options above (1, 2, and 3) do in fact presuppose the type of pre-theoretic intuitions about the universe outlined above. By taking the physics seriously, it turns out that formal considerations problematize fundamental ontological characteristics of the universe—something as (ostensibly) simple as modelling the universe as an open or closed system. Such formal considerations, I propose, should motivate one to be sceptical that the pre-theoretic concepts we have about the universe—about *X* and its physical properties—are such that our mathematical concepts can line up in a way that some authors seem to presuppose when suggesting that the wavefunction can represent reality directly.

A brief note on option 3, namely "*Y* directly represents *X* just in case *Y* and *X* are isomorphic": the notion of isomorphism is perhaps a little more refined, but it ultimately has no more to offer than the notion of direct representation. Halvorson (2019, p.147) convincingly argues that "isomorphism is a category-relative concept…two mathematical objects can be isomorphic *qua* groups, but non-isomorphic *qua* topological spaces." To make the sentence, "*Y* directly represents *X* just in case *Y* and *X* are isomorphic" precise, one requires a specification of the category for which the notion of isomorphism is intended. And there is no obvious category of mathematical objects to which the wavefunction belongs (see Halvorson 2019 §3). Moreover, given isomorphism is a relation between two mathematical objects, and given the view of option 3—that "*Y* directly represents *X* just in case *Y* and *X* are isomorphic"—it then follows that the universe is an *abstract mathematical object*, and in light of the discussion of option 1, I assume this is not the view endorsed by those who suggest that the wavefunction represents reality directly.

4.3 Absolute Generality and Objectivity

Let us now consider the idea of the wavefunction *directly representing reality* if one rejects the view that there is an objective ontology that lies beyond our descriptions of the world, that is, to borrow Rayo's (2019, p.6) phrase, a "metaphysically privileged articulation of the world into constituents" that is independent of our representational resources. This will pave the way to return to the discussion of objectivity in quantum mechanics more broadly.

In chapter 3 we saw how, according to Rayo's (2019) *Recarving Anti-Absolutism* thesis, the notion of an absolutely general domain is considered incoherent. For ease of presentation, let us briefly summarise the view. Recall Rayo (2019, p.10) argues that "there is no sense to be made of an articulation of the world into constituents that is significant from a purely metaphysical point of view and therefore significant independently of how the world happens to be represented."

Rayo (2022, p.7) proposes a view (an interpretation that respects logical entailments) that gives "a fully adequate and maximally robust connection between our language and the world it represents." Recall—moreover—that "in claiming that a fact is "carved up" into objects and properties by our use of language, the anti-absolutist should be understood claiming that certain aspects of the fact are *rendered salient* by the relevant language, as opposed to claiming that objects and properties are being *created* by language."

The way that particular aspects stand in relation to the ways the world can be is not something that generally depends on either minds or language, but crucially, the *salience* of a particular idea about the world is dependent on our descriptions of the world. On Rayo's (2022, p.11) view, Venus exists irrespective of minds or languages but its inclusion into an astronomical linguistic domain is dependent on the relations between states of the world which particular (salient) descriptions pick out:

> Venus is an aspect of the fact that Venus is a planet that is rendered salient by "Venus", in virtue of rendering salient commonalities between the ways for the world to be that are paired with "Venus is a planet", "Venus is unwelcoming", and so forth. The property of being a planet is an aspect of the fact that Venus is a planet that is rendered salient by "is a planet", in virtue of rendering salient commonalities between the ways for the world to be that are paired with "Mars is a planet", "Jupiter is a planet", and so forth.

Objects on the anti-absolutist picture are *open-ended*; anti-absolutism suggests that there isn't a particular ontology that is singled out independently of the methods used to represent the world. To distinguish one object from another is inextricably linked to our representational practices. If a domain of objects is established by a particular language which "renders salient" certain features of the world, one can use this to characterize a language which "renders salient" additional features of the world, thereby expanding one's original domain of objects. Whilst it may be true (for example) that there are electrons, oxygen, and Everett worlds, the particular descriptions we use to identify the relevant feature of the world have no metaphysical significance—there is no single, privileged description we attribute to those features of the world. The facts we attribute those descriptions to can be described using many different, entirely separate sets of distinctions and "there is nothing about the world as it is in itself, that makes the distinction between containing oxygen and not "objectively correct"." (Rayo 2022, p.28).

Rayo's proposal is situated within a collection of metaphysical views which argue that the notion of an all-inclusive domain—a domain of *totality*—is incoherent. Given there are also reasons (detailed in chapter 4) to challenge the coherence of an all-inclusive *physical* domain, in what follows I explore how Rayo's view can illuminate discussions of (anti)realism. If we take Rayo's view seriously, what do our physical theories say about the nature of reality?

In the previous section, I considered three criteria (following Halvorson 2019) for assessing what it could mean for the wavefunction to represent reality directly. In all three options, there is reason to think that what a direct representation aims to achieve is to represent reality or represent the world "*as it is in itself*" (Rayo 2022, p.28). That is, if the wavefunction is successful in representing reality directly, then there is a particular account of the world, an objective fact about the world that the representation correctly picks out. The relationship between *X* and *Y* as proposed in options 1, 2 and 3 is setup in such a way that the role of the representation is to establish a method by which to retrieve a correct description of reality. For those who suggest that the wavefunction represents reality directly (and in contrast to the view presented here), it's not the case that the representation itself should be central to the formation of one's ontology—the ontology is something which is independent of the representational practice.

Scientific representations are sometimes representations of objects in concrete, physical reality, and as we have seen, sometimes scientific representations are representations of concrete, physical reality itself. Many authors acknowledge the difficulty in allowing space for concrete, physical reality to enter into the picture; as I hope to have illuminated above, there are serious questions about the way in which mathematical objects (e.g., wavefunctions) can successfully map on to a non-mathematical reality.[13] Van Fraassen (2008) describes the problem as *the loss of reality objection*; Muller (2011) as *the problem of lost beings*; and Contessa (2010) as the

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[13] Although my example is from quantum theory, I take this to be indicative of a more general problem about the way mathematical objects can successfully represent a non-mathematical reality.

bridging problem. The problem, as I see it, is that despite suggestions that reality is *concrete*, *physical*, or *non-mathematical*, there is actually little reason to commit to any view which claims to illuminate a *true* nature of reality, so to speak. The problem with descriptions such as *concrete* or locutions such as 'true nature' is their tendency to evoke notions of fixedness and completeness, to a reality which *has* a particular, privileged metaphysical status, a reality that is there to be revealed, if only our representations were set up in the right way.

Whilst some may consider the view I propose here as metaphysically radical, my own attitude is that the view is conservative in its claims about the world. It attempts to illuminate the relation between science and the world, relinquishing the (arguably unfounded) assumption that there is a particular ontology that is singled out independently of the methods used to represent the world. If there is a particular privileged ontology, then those who support this view owe an account of not only what the ontology is, what reality actually *is*, metaphysically speaking, but also *why* that assumption is in place. The physical anti-absolutist on the other hand denies that there is a particular ontology that lies beyond those methods used to represent the world, instead proposing that there are alternative ways to describe a particular fact, to divide the world into objects and properties.

Given there is no single, privileged description of the world according to the physical anti-absolutist, when we aim to deliver a representation of reality (in the form of e.g., the wavefunction), the metaphysical description that the representation aims to pick out is not a distinction inherent in the world *itself*, it is not a distinction that can be disentangled from the representational practices used to describe the world. In Rayo's (2022, p.28) words, "there is nothing about the world, as it is in itself" that settles whether the existence of the wavefunction is "objectively correct". Rather, since the wavefunction can capture particularly useful facts about the world, it is desirable to describe the world as being represented (directly) by the wavefunction. The wavefunction (and the set of facts that it intends to capture) is a distinction that we find effective since our constitution and the world is in integrated in such a way as to make the wavefunction a particularly compelling way to describe the world. The language-relative conception of objecthood suggests that ontological questions can only be evaluated from within a particular language since there is no position from which various language-delivered ontologies can be compared. Demanding the true nature of reality seems to assume that there *is* such a thing as an ontology that transcends beyond those methods used to represent the world. For this reason, I consider the more radical view to be one that *commits to* a metaphysically privileged ontology.[14]

Recall the three criteria proposed by Halvorson (2019) for assessing what it could mean for the wavefunction to represent reality directly: option 1 says "*Y* directly represents *X* just in case every property of *Y* is also a property of *X*"; option 2 says "*Y* directly represents *X* just in case every mathematical property of *Y* corresponds to some physical property of *X*"; and option 3 says "*Y* directly represents *X* just in case *Y* and *X* are isomorphic".

In response to those who suggest that the wavefunction represents reality directly, I'm hesitant to agree that the question should be posed as *how* or *in what way* the wavefunction represents reality; rather first consider—through both physics and metaphysics—whether reality gives us reason to think that there is a particular description of the world that is independent of the questions we put to it.

In all three options, there is no sensible map between the properties of *Y* and the properties of *X* without making (for example) something like a category mistake (it follows from the first option that reality is an abstract mathematical object). One first, I think, requires an account of what the domain of *X actually is* before suggesting that the wavefunction fails to represent it. And given there is reason to doubt (through considerations of both physics and metaphysics) that reality can be given a 'true description', I suggest we relinquish this hypothetical description from our metaphysics.

How is this view of physical reality situated within debates about scientific realism in quantum mechanics? As discussed earlier, on the one hand of the debate there are scientific realists who are committed to interpreting scientific claims about the world *literally* (such as the wavefunction representing reality directly) and on the other hand, there are those who reject the idea that the quantum state is a state that offers a description or representation of an 'external reality' (such as the QBists). For the reasons discussed above, physical anti-absolutism rejects both pictures; it rejects the view that the world is independent of our way of representing or describing it[15], and secondly rejects the idea that the quantum state fails to provide a description or representation of an external reality. By rejecting the notion of a metaphysically privileged ontology one needn't reject the notion of an external reality.

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[14] It may be helpful to say what I mean by 'radical' here: it is the *positing* of a metaphysically privileged ontology that is radical. I think the more conservative view is one that has no commitment to a fact such as 'the true nature of reality' given there is little reason—or so I have argued—for it to play such a central role.

[15] This description of realism is owed to Contessa (2010, p.515) following Psillos (2000).

Let us consider my proposal in a little more detail in the present context of scientific realism. Central to the thesis is an assumption about how language relates to the world: sentences with very different logical forms are sufficient to describe a particular a feature of the world. To revisit Rayo's (2022, p.6) example from chapter 3, "the objective feature of the world that is fully and accurately described by saying "Socrates died" might also be fully and accurately described by saying "Socrates's death took place" (or "dying occurred Socratishly")."

Recall also Rayo's (2022, p.7) notion of *legitimacy*:

> **Legitimacy**: All it takes for $[\![\ldots]\!]$ to count as a *legitimate* interpretation of L - all it takes for it to constitute a fully and adequate and maximally robust connection between our language and the world it represents - is for it to respect logical entailments.[16]

What *legitimacy* then allows is for the same proposition to be assigned to e.g., "Socrates died" and "Socrates's death took place". A particular feature of the world can be singled out using different logical forms. Recall also the *unit of measurement* analogy of chapter 3: in asserting that the height of my chair is 1 metre ($\pm$1%), one also (implicitly) provides a structure for relating the height of my chair to the dimensions of other objects in the world. Asserting that the height of my chair is 3.28 feet ($\pm$1%) (implicitly) provides an alternative structure for relating the height of my chair to the dimensions of other objects in the world but the objective fact about the height of my chair does not change.

The unit of measurement analogy aims to provide an insight into the nature of objects and properties. There are many ways (many distinct measurement units) that can be assigned to a particular dimension, but a unit of measurement must satisfy its intended *theoretical* role as a *measure* through the assignment of numbers (in our case here) to properties. Similarly, a particular language gives us many different ways to describe a fact, but that language can only deliver an ontology upon dividing the world into a particular set of objects and properties.

It may be helpful to position the view against those scientific realists who are committed to interpreting scientific claims about the world *literally* and those who reject the idea that the quantum state is a state that offers a description or representation of an 'external reality' (such as QBists). In contrast to those who suggest that the world is (largely) independent from our way of representing or describing it, the anti-absolutist suggests that our ontological descriptions actually *depend on* our representational resources. Representations are at the forefront of establishing which aspects of the world are brought into focus and as such is the process by which

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[16] Rayo (2022, p.7).

an ontology is delivered. Objects and properties connect different features of the world but there is no privileged metaphysical description of it. To echo Rayo (2022, p.17): "if our systems of representation don't render them salient, nothing will." My suspicion is that those who suggest that the world is in fact independent from our way of representing or describing it, do consider there to be a privileged metaphysical description of the world. My charge here is that those who endorse such a view have failed to explain why it is assumed that there is a privileged metaphysical description of the world and how it is that that particular description is privileged, if not from our representational systems.[17]

In what ways does the view differ from those who reject the idea that the quantum state fails to provide a description or representation of an external reality? Before detailing the differences, it's worth highlighting that the anti-absolutist does share the QBists' renunciation of the so-called "God's-eye view". The QBists reject such a picture in order to motivate the suggestion that the quantum state only refers to the multiple *subjective* degrees of belief associated with each agent's future experience (there is no unique, observer-independent, quantum state). Physical anti-absolutism rejects the God's-eye view for the reasons set out in chapter 3, namely that there are arguments from physics to challenge the coherence of an absolutely general physical domain and the point from which such a domain could possibly come into view.

There are salient differences, however. Recall there are (convincing) reasons to think that on the QBist picture the fundamental level of physical reality is, in Brown's (2019) words, "ineffable". Rather than rejecting the idea that the quantum state is a state that offers a description or representation of an 'external reality', the physical anti-absolutist holds that the *distinction* between there being a quantum state or not is a theoretical tool—the distinction is made fruitful by its consistency with our observations about the world, and its usefulness can be measured by its ability to help us make sense of reality.

Finally, how should the view be characterised within debates about (anti)realism in quantum theory? It seems antirealism is a difficult badge for some to wear (notably Fuchs 2017 implores his readers not to associate QBism with such a view; see also Healey 2012) but if the realist view is one that says the world is (largely) independent from our way of representing or describing it, then the view expressed here can be characterized as antirealist if antirealism

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[17] Some may object that the notions of *universals* and *natural properties* intend to do something like this but it's not clear why—if there are such properties—current methods in physics or metaphysics will happen to (or are ever going to) reveal these properties. Moreover, it's not clear that there is a consensus on what constitutes a natural property (some hold that normative or evaluative properties such as goodness or betterness are perfectly natural—see Ridge 2019), which I take to further motivate relinquishing the commitment to a metaphysically significant articulation of the world.

simply means the denial of realism. This is a strange outcome though, antirealism used in this way says little *positively* about the world; it seems to be characterized primarily by its denial of a particular view of the world.[18] Physical anti-absolutism aims to express what there is—what realism is about—rather than to be characterised in the shadow of a view it seeks to deny (namely, that there is a "true nature" to reality; the "ultimate furniture" of the world). We can therefore be a little more nuanced. Perhaps a more illuminating setup might be to frame the question in terms of metaontology: in other words, are there objective answers to the question, "what exists?". The realist (perhaps) says yes whilst the antirealist (perhaps) says no. To this question however, the physical anti-absolutist expresses firmly that there are objective answers to the question of "what exists?", and those answers are reached by the method elucidated.

It's likely that physical anti-absolutism is situated somewhere in the middle of the realism-antirealism debate, denying the extremes of each wing and instead endorsing features affiliated with both realism and antirealism. Chalmers (2009) suggests the term *lightweight realism* to capture deflationary, intermediate views in the context of ontological (anti)realism; something similar may be appropriate here.

In the following chapter, I consider the application of the approach I have been developing to Everettian quantum mechanics.

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[18] Given this characterisation, there are many different positions that qualify as antirealism. See e.g., Kitcher's (2001) classification in the context of scientific antirealism more broadly (in contrast to the discussion here which has been limited primarily to (anti)realist views about *quantum theory*).

5. Everettian Quantum Mechanics

This chapter uses Everettian quantum mechanics as a case study to illustrate the ideas raised in chapters 2-4. In sections 5.1-5.2, I aim to identify some ways of thinking about totality in the context of EQM by exploring some metaphysical consequences of Cuffaro and Hartmann's (2021) aforementioned (§3.8) *open systems view*, namely quantum theory under the view that open systems are fundamental. I argue that despite the success of quantum theory in modelling systems as closed, an alternative approach is to say that quantum systems are *open systems* and as such one shouldn't insist on a metaphysical picture which conceives of closed systems as being fundamental. I then import Rayo's (2022) machinery to suggest that there is a salient connection between our representational resources and Everett worlds, and that entities in the physical domains described by EQM are equally as susceptible to the open-endedness of objects as viewed by the anti-absolutist.

Section 5.3 considers the intuitive tension in conceptualizing reality to be open-ended or incomplete. Cuffaro and Hartmann (2021, p.46) suggest that on the open systems view, "the ontological distinction between open and closed systems breaks down" when describing the universe as a whole. I propose that whilst there is a *prima facie* tension between incompleteness and the way reality is typically conceived, there are in fact good reasons for rejecting the notion of 'the universe as a whole'. The idea that there is a physical total domain we call the universe (as a whole) operates as a guiding principle within which we can generate concepts such as open and closed systems. Once this principle is removed, it's not obvious that there is a coherent distinction between open and closed systems.

Finally, §5.4-§5.9 proposes a reading of *world number* in Everettian quantum mechanics. The number of worlds in EQM is often (unsatisfyingly) described as indeterminate. In response, I suggest that the indeterminacy of world number results from illegitimately reifying features of one mode of representing an Everett world in the context of another mode. Moreover, this distinction motivates a view which doubts that there is a metaphysical fact about the number of Everett worlds which is over and above our representational resources—a feature consistent with physical anti-absolutism; that the notion of an absolutely general physical domain is incoherent. Taken together, this chapter firstly aims to strip away any metaphysical bias in EQM that may have been unjustly endorsed over the years; secondly, to consider and overcome both technical and metaphysical objections in understanding EQM and totality in view of physical anti-absolutism; and thirdly, to offer how physical anti-absolutism is consistent with EQM's most prominent feature, multiple effectively-independently-evolving worlds.

5.1 EQM and the Open Systems View

In chapter 3 I discussed Cuffaro and Hartmann's (2021) *open systems view*, which takes open systems—systems that interact with their environment—as fundamental. This section aims to discuss EQM and the open systems view in more detail, and draw out some of what I take to be the more interesting metaphysical consequences.

For ease of presentation, recall the authors' distinction between *standard quantum theory* (ST) and the *general quantum theory of open systems* (GT). The corresponding *view* of the ST *framework* is the "*closed systems view*" in which closed systems are treated as fundamental. Recall, on this view, the "associated…methodology that models the dynamics of a given open system, *S*, in terms of it being coupled to a further system *E* (representing its environment), such that *S* + *E* form an isolated quantum system." (Cuffaro and Hartmann 2021, p.6).

The corresponding *view* of the GT *framework* is the "*open systems view*" in which open systems are treated as fundamental. Recall, this view's "methodology is such that, rather than modeling the dynamics of a given open system *S* in terms of an interaction between two systems, we instead represent the influence of the environment on *S* in the dynamical equations that we take to govern its evolution from one moment to the next." (Cuffaro and Hartmann 2021, pp.6-7).

One often appeals to the mathematical object of a unitarily evolving state vector (pure state) in quantum theory to represent quantum systems.[1] To do this one embeds the target system in a larger system: for a quantum system obeying non-unitary dynamics, the system is "purified" by coupling the target system with a larger (closed) system and the total system evolves unitarily. Describing quantum systems in this way is consistent with ST, in which closed systems are treated as fundamental. Generally, systems in quantum mechanics are representable by a density operator, which acts on the system's Hilbert space, but this isn't the case for pure states unless one appeals to a larger closed system (Hilbert space)—thus treating closed systems as fundamental.

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[1] Many Everettians (as discussed in chapter 4) take the universe as a whole to be represented by a unitary state vector—recall Carroll (2021) who suggests that reality is represented directly by the wavefunction. I discuss this point in detail in what follows.

Open systems on the other hand are generally always representable by a density operator. Chen (2018) is perhaps most notable in advocating a view he terms *density matrix realism* which in contrast to wavefunction realism (in which the universal quantum state is objective and pure), suggests that the universal quantum state is objective and *impure* (mixed).

Open systems according to standard quantum theory (ST) are describable by operating (via the partial trace operation) on the dynamics of the system *S* plus the environment *E*. The total system *S*+*E* is then represented by a unitarily evolving state vector, ψ_{S+E}. According to ST, the dynamical map on an open system on this view is completely positive. According to GT, the physical state of a system *S* is represented by a density operator ρ. The system's evolution is governed by a dynamical map Λ_t such that $\Lambda_t \rho_0 = \rho_t$. And crucially, Λ_t acts on the state space of *S* rather than *S* + *E*; the system, in general, evolves non-unitarily. Open systems are not considered, in Cuffaro and Hartmann's words, "in terms of a contraction (via the partial trace) of the dynamics of a larger closed system", as they are in ST; in GT *open systems are fundamental*—there is fundamental non-unitary evolution.

Whilst I do not wish to make it my focus to defend the open systems view, it is helpful, I think, to suggest a response to one of its most pressing objections. The objection is something like the following: the empirical success of quantum theory under the closed systems view is clear. Should we not take this success to motivate a view that says closed systems are fundamental? The right response here is to emphasize that the systems that we apply quantum theory to are open systems.[2] It's true that quantum theory has made significant progress by either modelling a system as isolated (in an effectively empty universe) or tracing out a system's environment, but there is little reason why this success should be attributed to the fact that implicit in explanations of quantum phenomena these systems are closed. An alternative picture is to say that quantum systems are open systems (even if the environment's influence on a quantum system is negligible, it is still an open system) and given one can formally represent these systems under a view in which open systems are taken to be fundamental, one should be hesitant to insist that the closed systems view is the preferred metaphysical description of reality.

In fact, notable Everettians give us reasons to think that a description of the universe as a whole shouldn't necessarily prioritise ST over GT. Carroll (2021, p.5) suggests that "technically it [our universe] is more likely to be in a mixed state described by a density operator, but

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[2] Even though science proceeds by *modelling* quantum systems as isolated, no physical system *is* isolated from quantum mechanical relations. Some authors might suggest that this is true apart from the universe as a whole—however, in contrast to *physical anti-absolutism*, those authors must assume the universe as a whole is a coherent notion.

that can always be purified by adding a finite-dimensional auxiliary factor to Hilbert space, so we won't worry about such details."[3] Similarly, Wallace (2012, §10.5) is open to the possibility that the universe as a whole is in a mixed state, appealing to black hole physics: if, after preparing a pair of spin-half particles in a singlet state, one particle is thrown into a black hole, the other particle will now be in a mixed state, whilst the universe as a whole remains pure. If then one endorses the view that the black hole will evaporate by Hawking radiation (Hawking 1976), the particle thrown into the black hole will cease to exist; that particle's entanglement won't have been transferred to another system. The other particle will continue to be in a mixed state, but now since there is no pure state, we cannot take the partial trace to return a mixed state. The universe as a whole—it would seem—is now in a mixed state; black hole evaporation entails a pure to mixed state transition. One could say a lot here, but as noted by Wallace, a lot depends on whether the quantum theory of gravity permits quantum systems to *cease to exist* as opposed to changing state. If it does, then pure-to-mixed state transitions and universal mixed states seem inevitable.[4]

5.2 Everettian Branching and the Open Systems View

There is a *prima facie* tension acknowledged by Cuffaro and Hartmann between the multiverse of effectively isolated evolving worlds as proposed by EQM, and a non-unitary evolving universe in a mixed state. For some, EQM *just is* unitary quantum mechanics (Wallace 2012, p.3 writes "I will refer to the subject matter of this book as 'Everettian quantum mechanics…or just 'unitary quantum mechanics'…").[5] If the universal state is represented by a non-unitarily evolving mixed state, then what's left of the Everettian picture?

Despite Wallace suggesting that EQM and unitary quantum mechanics are synonymous, as noted above he also suggests (Wallace 2012, §10.5) that it's not inconsistent with EQM to represent the universe by a (non-unitary) density operator—the outcome of which will

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[3] My sense here is that Carroll does not take this move to have a physical correlate. In other words, I take it that there isn't a physical process, which is represented by "adding a finite dimension auxiliary factor to Hilbert space", that subsequently purifies the state. I take this to further motivate the thought that a description of the universe as a whole shouldn't necessarily prioritise ST over GT.

[4] Wallace also draws similar (but more tentative) conclusions from the quantum mechanics of time travel (see Wallace 2012 §10.6)

[5] Elsewhere, Wallace (2012, p.104) writes "Unitary quantum mechanics is testable, and Everettian quantum mechanics just is unitary quantum mechanics, so tests of the former are tests of the latter." Wilson (2020, p.99) also suggests, "An initial quantum state, in combination with unitary evolution, determines a complete multiverse".

depend on future evidence. My proposed answer to this question is intended as a friendly amendment to the strategy of Cuffaro and Hartmann in the hope of making their proposal about EQM more precise. Cuffaro and Hartmann's suggestion is to draw an analogy with worlds. Given worlds according to contemporary decoherence-based EQM are emergent entities and considered 'real' by appealing to their use for whichever practical purpose they serve (e.g., Wallace, 2012, §2.2), this description of worlds can be employed regardless of whether the universal state is either mixed or pure.[6] In other words, if it's useful to understand reality in terms presented by a unitarily related multiverse, which encodes multiple quasi-independent classical worlds understood in terms of whichever theoretical purpose they serve, we can always recover a branching structure. If the universal state is mixed, one can purify and evolve it forward to generate a branching structure. This purification of the universal density operator (to a pure state on a larger Hilbert space) is taken to be non-fundamental—just like the worlds it encodes. If there are pragmatic reasons to think of the branching structure as real (Wallace 2003, 2012), then according to Cuffaro and Hartmann, Everettians are justified in doing so.

Whilst I largely share this view, I think their suggestion can be made more robust. It seems that whilst Cuffaro and Hartmann (2021) are satisfied with Wallace's (2003, 2012) appeal to emergence for delivering a branching structure, the idea that multiple quasi-independent classical worlds should be understood in terms of whichever practical purpose they serve is, I suggest, coherent but underdeveloped. My suggestion is that we can make this intuition more precise by applying the ideas presented in chapters 3 and 4 to EQM, that is, by considering the connection between our representations and ontology, and the notion that entities in the *physical* domains described by our physical theories are equally susceptible to the open-endedness of objects on the anti-absolutist picture of §2.3.

Physical anti-absolutism aims to formalize the bridge between the concept of *usefulness* and the object it aims to pick out (namely, an Everett world) that Cuffaro and Hartmann, and Wallace gesture at. It proposes a model which delivers an ontology, delivers elements of reality, from understanding how language relates to the world. The *distinction* between there being an Everett world or there not being an Everett world is a theoretical tool—the distinction is made

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[6] Wallace (2012, p.50) appeals to Dennett (1991) to present his view ("Dennett's criterion"): "A macro-object is a pattern, and the existence of a pattern as a real thing depends on the usefulness—in particular, the explanatory power and predictive reliability—of theories which admit that pattern in their ontology." One might suggest that this isn't an entirely accurate account of Wallace's view, instead emphasising that, according to Wallace, worlds are real because decoherence is objectively suppressed in an interest-independent way. I concede that this forms part of Wallace's view, but this doesn't detract from the reasons why we take *worlds* to be interesting. The significance of the decoherence process cannot be disentangled entirely from the fact that we consider worlds to be useful entities to admit to our ontology.

fruitful by its consistency with our observations about the world, and its usefulness can be measured by its capacity in helping us make sense of reality. And in virtue of delivering an ontology in this way, physical anti-absolutism suggests that the idea of an absolutely general Everettian domain is incoherent; there is no sense to the domain of totality as according to Everettian quantum mechanics.

If the *distinction* between there being an Everett world or there not being an Everett world is a theoretical tool that is included within our ontology from understanding how language relates to the world, one should be open to consider foundational questions in EQM in view of all available metaphysical pictures. (As I argue in chapter 7, physics is our best guide to metaphysics and if analogous arguments from fission cases constrain the metaphysics in a way that is not supported by the physics, such analogies should be abandoned).

There is however at least one objection one might raise about the different metaphysical pictures of EQM and the notion of open-endedness or incompleteness proposed here. The objection is something like the following. Recall the distinction between *overlap* and *divergence* (§3.3); *prima facie* it would seem that the metaphysical picture of overlap is more hospitable to a thesis of open-endedness given its dendritic structure of "splitting" worlds. In contrast, given there is no "splitting" according to divergence, the structure is more akin to parallel worlds in which the number of worlds at time t_0 is the same at time $t+1$, or to put it another way, the absolutely general (Everettian) domain—and structure of worlds—is already specified at time t_0.

There are a number of points to raise here. Firstly, as we saw in §3.3 (and is central to the rest of this chapter), the number of worlds in EQM is indeterminate and so the number of worlds at time t_0 and at time $t+1$ is still sensitive to the coarse-graining of the decoherence basis and so if one partitions worlds at time $t+1$ at a finer grain to time t_0, there will be more worlds associated with time $t+1$ than there will associated with time t_0.

Remember also that the metaphysical pictures of overlap and divergence aren't competing—they are different ways of carving up the same structure (the fundamental quantum state) and the way I propose that this structure is carved up is by relinquishing our commitment to a metaphysically significant way for the world to be. Whilst it may appear that divergence is less hospitable to open-endedness or incompleteness, this is, I think, only due to the schematic nature in which these two views are characterized (as by either splitting or parallel worlds).

The intuition that the metaphysical picture of divergence is one that suggests a *complete* or *closed* reality and therefore runs contrary to the incoherence of an absolutely general physical domain is part of a more general intuition about the whole of reality and the notion of incompleteness, which I turn to next.

5.3 Incompleteness in the Everettian Picture

Recall Cuffaro and Hartmann's (2021 §5.3) concluding remarks that there are difficulties in interpreting the non-unitarily evolving cosmos as either an open or closed system. If we model the cosmos as a closed system, we require terms in addition to those corresponding to the Hamiltonian of the system, which are typically attributed to the interaction between the system and its environment—an obvious problem if the system is already defined as a totality. If on the other hand we interpret the cosmos as an open system then we're confronted with an equivalent problem: a system's environment is central to the description of an open system, but in what does this environment consist if totality has already been specified? Cuffaro and Hartmann (2021, p.46) conclude that if open systems are considered fundamental, then "the ontological distinction between open and closed systems breaks down" when describing the universe as a whole.

I propose that the reason for a break down in the ontology of open and closed systems when describing the universe as a whole is that the description of *the universe as a whole* does not have a physical correlate, it does not admit of a total description. Whilst after several chapters this idea has already been illuminated to some degree, I suspect there are readers who still cannot dismiss the most pressing, most basic intuition: how can reality be such that there is no sense to the notion of *all of reality*? —no sense to the notion of *all that there is*? —no sense to the notion of the *total*?

The first point to consider is one that will be familiar to Everettians[7], namely that the nature of reality won't necessarily satisfy our pre-theoretic intuitions. Intuition, absent supporting arguments, is no guide to what the world is actually like.[8] And given there are good reasons from both metaphysics and physics to consider there to be problems making sense of the idea of an absolutely general physical domain, no sense to the idea of *totality*, one shouldn't be dogmatic in asserting that there is such a thing. Whilst this response may satisfy some, I suspect

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[7] E.g., Wallace (2012, First Interlude)

[8] One often cites twentieth century physics in support of this argument, but this may—at least in part—be attributed to so-called *chronocentrism*. I don't see how the eventual acceptance of Copernicus' heliocentric solar system would prove to be any less of a shock to our intuitions about the nature of reality. For criticism of intuitions in philosophical methodology, see Ladyman and Ross (2007) and Williamson (2007).

there are still those readers who are unsatisfied. Appealing to the unreliability of our intuitions might be appropriate for the discovery of quantum mechanics or relativistic physics but to renounce a notion such as *totality* is a very different type of challenge to intuition. For example, one might suggest that whilst it's intuitively hard to accept that according to quantum mechanics particle position can only be given a probabilistic reading, such a feature only hinges on relinquishing the notion of point-particles from our worldview. In contrast, by accepting physical anti-absolutism, one must relinquish an entire *framework* rather than a feature of a particular entity in one's ontology (a feature inherited from classical physics). Moreover, updating one's description of a particle by analogy with e.g., wave mechanics generates some insight into the nature of particles, but there is little by way of analogy that can motivate one to accept that the universe as a whole is incomplete, or open-ended.

Whilst I accept that the tension is severe, I suggest that this can be assuaged by the following. One needn't think that an incomplete universe is one in which some part of the universe is unaccounted for; the view does not suggest that in rejecting the notion of totality, one endorses the idea that reality is actually totality *plus environment*. Rather physical anti-absolutism proposes that there is no (totality) fact available which says, *that is all there is*. Relinquishing this fact from one's worldview is a much more metaphysically conservative way to yield the same result, namely that the notion of an absolutely general physical domain is incoherent.

In response to Cuffaro and Hartmann's suggestion that there is a break down in the ontology of open and closed systems when describing the universe as a whole, I think there are good reasons above for rejecting the notion of the "universe as a whole". The authors suggest that not every mathematical concept (e.g., density operators, state vectors) in our ontological investigation will line up with those pre-theoretic concepts we have about the universe. In view of the arguments presented above, the reason such mathematical concepts in our ontological investigation fail to line up with those pre-theoretic concepts we have about the universe, is that there are reasons from physics and metaphysics to challenge basic pre-theoretic concepts about the universe such as there being such a (physical) thing as totality. In virtue of there being no sense to the idea of an absolutely general physical domain, it's perhaps unsurprising that the there is a break down in the ontology of open and closed systems since the concepts of open and closed systems manifest within a framework that presupposes that there is in fact an absolutely general physical domain—an ostensibly *closed* system—the universe as a whole. Closed systems (such as the entire universe) appeal to the notion of a physical totality, affirming its status as a closed system. Similarly, an open system is one that partitions totality into: selected subsystem *plus* environment. The idea that there is a physical total domain we call the universe (as a whole) operates as a guiding principle within which we can generate concepts such as open and closed systems. Once this presupposition is removed, it's not obvious that the distinction between open and closed systems is coherent.

In the final part of this chapter let us connect considerations about totality to an aforementioned and prominent feature of EQM, namely the indeterminacy of world number.

5.4 World Number in Everettian Quantum Mechanics

In decoherence-based EQM, quantum theory is understood without collapse of the wavefunction. Fundamental reality constitutes all quantum possibilities. As alluded to by Simon Saunders (1993, 1997, 1998) and emphasized by David Wallace (2003, 2010, 2012), Everett worlds are not defined in microscopic terms however, they are *emergent* structures to be understood using methods central to accounts of emergence in the physical sciences more broadly. This gives us some reason to think that counting the number of worlds may prove problematic. Consider an analogy: the number of clouds in the sky. How many clouds are in the sky? Or alternatively, which collections of wisps constitute a cloud?

Let us revisit the relevant details of EQM. Everett worlds result from the discretization of configuration space but there is a relation between the choice of coarse-graining of the decoherence basis and the enumeration of Everett worlds. If the partition (of the decoherence basis) is chosen at a particularly fine-grain, more worlds will be counted than if the partition is chosen at a coarser-grain. Moreover, if the description is either too coarse-grained or too fine-grained then the decoherence conditions will cease to be met—but there is no precise point at which these conditions occur. Thus there are two (related) strands to the difficulties we face in discussions of world number in EQM. Firstly, world number is sensitive to the coarse-graining of the decoherence basis and secondly, there is no precise point at which the discretization is too fine-grained or too coarse-grained, and thus no precise demarcation of worlds.

Whilst most proponents acknowledge some unclarity around the number of worlds in EQM, the discussion is often underdeveloped and largely unsatisfying. The point of departure for this section is to suggest how a more illuminating explanation of indeterminacy must acknowledge the distinction between the *immanent* representation of an Everett world and the *fundamental* representation of an Everett world. Firstly, I propose that the indeterminacy of world number results from illegitimately reifying features of the immanent representation in the context of the fundamental representation—this is a diagnosis of the problem. Secondly, this distinction motivates a view which doubts that there is a metaphysical fact about the number of Everett worlds, which is over and above our representational resources—this is the metaphysical picture resulting from the diagnosis.

It seems that whilst there is a coherent response to give those who question the number of worlds in the multiverse, the answer isn't straightforward. Most discussions agree that there is a presumption in the question that isn't compatible with the Everettian framework. Recall from §3.5 that some comments (e.g., Saunders 2010, p.12) suggest the question, "how many worlds?" has no good answer; counts of worlds are instead "arbitrary conventions" (Saunders 2010, p.313), which are "not well-defined" (Greaves 2004, p.450). Other comments are less sympathetic, suggesting that the question (ultimately) fails to make sense (Wallace 2010, p.68); similarly, it is claimed there is no "physical significance' to the number of worlds, "it is not part of what is really there" (Saunders 2005, p.235). Wilson (2020 p.174) on the other hand denies the question is nonsensical but acknowledges there is "something defective" about it, suggesting world number "is *bivalently indeterminate*: that there is some n such that n is the number of worlds, but there is no n such that n is determinately the number of worlds".[9]

With Wilson as the exception here, implicit in those accounts that are sympathetic to the incoherence of the question, "how many worlds?", is the idea that in virtue of its incoherence one needn't address the question with rigour. In other words, one can legitimately refuse to give an account of world number in EQM given the question fails to make sense. But there are serious concerns with a response such as this; refusing to give an account is a substantial metaphysical move that warrants further attention. There are meaningful questions in the vicinity of those ideas declared meaningless and the question of world number in EQM is no different.

Let us then identify some consensus to the above responses and consider a question in response: the question, "how many worlds?" is *defective* or *inadequate* in some sense; no world count is either physically or metaphysically privileged; there is no finest-grain description or coarsest-grain description; world count is indeterminate. However, if the world around us is an Everett world as the theory suggests, the consensus[10] view is deeply unsettling: how does the

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[9] In contrast to the aforementioned authors, Wilson (2020 §5.2) gives more detailed consideration to world number, which we will address again at the end of this section.

[10] I don't claim that this is a consensus view amongst Everettians in general, but rather claim that there is at least some consensus to the views cited—most notably by the Oxford Everettians.

world we see around us fit into a structure of things of which there is an indeterminate number of them?[11]

5.5 This World

It's commonplace to makes reference to *our world*, or *this world* in discussions of EQM[12]: Wilson (2020 p.61) suggests "Everett worlds are worlds like this one, just more things of the same general sort"; Later, in discussion of *diverging* Everett worlds: "…we are asking if there is a sea-battle located in the future of the one and only Everett world that we ourselves occupy" (Wilson 2020, p.90). Similarly, "These worlds…are constantly splitting into multiple versions of themselves; our own world is just one amongst this multitude" (Wallace 2012, p.46).

Prima facie, there is determinately one world of which we inhabit, but an indeterminate number of them. On some coarser-grained decomposition of the quantum state there will be fewer worlds than on some finer-grained decomposition of the quantum state, so how should we think about (for example) the subset of worlds in which agents like us make claims such as "our world is just one amongst this multitude"? In other words, how fine-grained is our description of the quantum state when we speak "of the one and only Everett world that we ourselves occupy"?

The standard response is to say this isn't a well-formed question. The claim that our own world is just one amongst the multitude is again relative to the decomposition of the quantum state. On a coarser-grained description, our world is one of many; on a finer-grained description, our world is one of many, many more. It's a mistake to think that *this* world can be described as either one or many worlds[13]; *this world* is an emergent entity, it's not the emergent *world* that is decomposed but rather worlds emerge from the decomposition of the quantum state. For the same reason, it's a mistake to speculate how fine-grained the decomposition of the quantum state must be in order for this world to be 'counted'.

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[11] I take the consensus view to be unsettling since *prima facie*, there is determinately one world of which we inhabit, but an indeterminate number of them. Moreover, if we take metaphysical indeterminacy seriously, this has a significant impact on the status of our world. See §5.5 for details.

[12] Why is the indexical "this world" more significant than say, "this country" or "this room"? I think one can appeal to maximum causal closure here by suggesting that a world's set of relations is in principle maximally causally connected, which gives us at least some reason for postulating the metaphysical significance of an Everett world. Posited in this way is at least consistent with prevalent metaphysical views which give a metaphysically significant role to causal powers, e.g., Alexander's Dictum.

[13] This is for explanatory purposes; I'm not suggesting that there are authors who think that our world is many worlds.

This is still, I think, an unsatisfying response; there remains a lingering problem, namely how should we conceptualise our world—the world we see around us—whose place in the multiverse is ostensibly sensitive to how fine-grained the quantum state is decomposed? In order to begin to answer this question, let us first look at a recent paper from Dizadji-Bahmani, who challenges the indeterminacy of world count in the context of the Everettian probability problem.

5.6 The Problem of Indeterminacy

Dizadji-Bahmani's (2015) proposal looks closely at the role decoherence plays in supporting the claim that world count is indeterminate. The putative account of decoherence says that when a small system becomes entangled with a larger environment, very quickly multiple effectively non-interfering worlds emerge. In the context of Schrödinger's cat, each world is macroscopically consistent with either an alive or a dead cat. Dizadji-Bahmani (2015, p.277) is quick to highlight the interpretative method employed when taking elements of the decoherence model to represent effectively non-interfering worlds. The cross-diagonal terms represent the interference between worlds; the diagonal terms represent the worlds. The diminishing of the cross-diagonal coefficients thus represents the emergence of effectively non-interfering worlds. If there are more worlds, there are more diagonal (and cross-diagonal) terms, and "many (more) dead cats and many alive cats, in corresponding, numerically distinct, although qualitatively identical, branches." If this is the correct interpretative method however, Dizadji-Bahmani argues, then the number of worlds can't be indeterminate. Decoherence is a physical process from which patterns emerge from the fundamental quantum state; patterns are *multiplied*. If the process is interpreted in this way, he suggests, there is no metaphysical sense to the idea of there being no such thing as the number of Everett worlds.

The typical response here is to say that world count is dependent upon the choice of grain of the decoherence basis. Whilst the number of worlds is ill-defined, there are still worlds. Comparably, the number of clouds in the sky is ill-defined but there are still clouds in the sky. This, however, argues Dizadji-Bahmani (2015, p.278), is a "contentious slide from a metaphysical claim—claim about what is really happening out there in the world—to a worry about definitions." He continues:

> If the Everettians are right, then branching is a real phenomenon; there are emergent patterns in the quantum wave-function. How many? I do not know. But I do know that cats aren't the kinds of

> things the numbers of which can be indeterminate. There aren't half cats, or $\frac{2}{3}\pi$ cats. If there are cats at all, there are a determinate number of them."

This response misses the point. The possible existence of half-cats (or half-worlds) does not follow from the indeterminacy of world number. Everettians do not suggest that the number of Everett worlds is a non-integer finite number; each coarse graining of the decoherence basis delivers either a finite natural number or an infinite count[14], but in either case, on those views which advocate metaphysical indeterminacy, there are (determinately) no half-cats or $\frac{2}{3}\pi$ cats.[15]

More importantly for our purposes here however is Dizadji-Bahmani's assumption that there is a particular fact about an objective reality, a metaphysical fact about what is "really happening out there in the world"—a metaphysical fact which is over and above how the world is represented. We see the same assumption implied in Wilson's (2020, p.177) critique of Wallace's use of the notion, *arbitrariness*, in describing world number in EQM:

> Wallace prefers to say that it is not vague but arbitrary how many worlds there are (Wallace 2012: 101). However, this seems to have some implausible consequences. Arbitrariness is in the primary sense a property of choices, or of decisions: if a choice is arbitrary, then it is up to us how we make it. But it is not, in any coherent sense, up to us how many Everett worlds there are. (It may in some sense be up to us what we mean by 'Everett world': but given any determination of what is to count as a world, it is not up to us how many such objects there are.)

Again, there is an assumption—albeit weakened by the final sentence[16]—of a similar form to that seen in Dizadji-Bahmani (2015) above, namely that there is a metaphysical fact about the number of Everett worlds. Each account appears to endorse a metaphysical fact about the number of Everett worlds which is over and above how we choose to represent those worlds.

The representation of worlds is the focus of the next section and forms the basis to my proposal of understanding the indeterminacy of world number in EQM.

5.7 Modes of Representation

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[14] It's an open question whether the Hilbert space for our universe has a finite or infinite number of dimensions. It therefore remains a possibility that there are an infinite number of worlds.

[15] For what it's worth: it's also not clear why Dizadji-Bahmini thinks that the concept of a cat is sufficient to pick out a precise structure; won't a dicephalic cat present a problem to those wishing to count the number of cats? Somewhat ironically in our context here, there is longstanding debate about *Tibbles* the cat which, in various forms, poses this question. See Wiggins (1968).

[16] I address this qualification in §5.8.

There are, as I see it, two particularly salient representations at play in discussions of world number in EQM.

Firstly, there is the representation of our own world, a single Everett world according to a system embedded within that particular world; let us call this the *immanent representation*.

Secondly, there is the representation of the fundamental[17] quantum state, in which one finds patterns construed as emergent structures, namely Everett worlds. Let us call this the *fundamental representation*.[18]

I suspect one reason why some authors find it difficult to accept that the number of worlds in EQM is indeterminate is due to the tension generated from the fact that a system embedded in a particular Everett world has the resources to represent that Everett world *immanently*. Consider the number of clouds analogy once again. The number of clouds in the sky is only ever represented to a hypothetical exogenous system, that is, in representing the number of clouds in the sky, we are positioned outside the system of inquiry and without the resources to generate immanent representations of clouds. If it were possible to generate immanent representations of clouds, this may be an uncomfortable additional resource for those who maintain the indeterminacy of cloud number since the immanent-cloud representation itself seems to carry with it a particular demarcation of what constitutes a cloud.[19]

This idea carries over to EQM: the immanent representation of an Everett world is a representation that itself carries with it the notion that there is a particular demarcation of what constitutes an Everett world. The immanent representation is a representation that itself refers to a particularly demarcated object since the system doing the representing is by definition contained within the representation. It therefore becomes difficult to represent an Everett world as anything other than that particularly demarcated object when represented immanently since there is a one-to-one correspondence between the *representer* and the *represented*. The determinacy of locutions such as "this world" cited earlier is an artefact of this mode of representation.

The concept of the *multiverse*, as it is at least typically implicated in discussions as a *collection* or *multitude* of Everett worlds, is, I suggest, a representation that results from the reification

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[17] The notion of fundamental here is specific to the theory of EQM.

[18] It's worth noting that Wilson (2022) makes similar distinctions here (including the representation of the multiverse, which I discuss later) but in terms of *levels* rather than representations.

[19] I leave the way in which this representation is generated intentionally open (subject to further enquiry). It's perhaps intuitive to think that an immanent representation of a cloud is linked to a cloud being "conscious", for example, or at least the *physical* capacity to *produce* a representation, but an exploration of the connection between immanent representations and consciousness (or a representation-producing process) is too big a project to be included here; such an exploration is not the direction I wish to pursue and would distract from the main argument.

of the *immanent* representation at the level of the *fundamental* representation. The immanent mode of representation (and the determinacy with which it carries) is reified at the level of the fundamental mode of representation.[20] But one should be careful here. The immanent representation and the fundamental representation are indeed compatible but problems result when structures of one mode of representation are reified in the context of the other. Recall my suggestion that the determinacy of locutions such as "our world" represented as a particularly demarcated object is an artefact of the immanent mode of representation. The nature of this representation carries with it the notion that there is a particular demarcation of what constitutes an Everett world; the representation itself is tied to descriptions such as "this world" or "our world" since the representation of one's place within an Everett world is inextricably linked to the representation of that particular world. When Everett worlds are represented according to the fundamental representation, the representation makes the target system exogenous; the nature of this representation does *not* carry with it the notion that there is a particular demarcation of what constitutes an Everett world, and it is here where indeterminacy is able to gain a foothold.[21]

I've proposed that the determinacy of locutions such as "this world" cited earlier is an artefact of the immanent mode of representation. The suggestion here is not that the representation maps on to a fully-determinate, discrete world-object—we know that the rapid diminishing of the coefficients of the cross-diagonal terms represents the emergence of *effectively* non-interfering Everett worlds; interference does not vanish entirely. The way those worlds are typically represented however, is via a representation that is demarcated in such a way that warrants the use of descriptive concepts such as *one* or *this*, concepts which typically refer to discrete objects (or effectively discrete objects).

There is, as I see it, a particularly salient distinction between the immanent representation on the one hand and the fundamental mode of representation on the other. In contrast to an Everett world that is represented as part of the structure picked out by the fundamental representation, any system that represents an Everett world immanently is included within the

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[20] For example, Wallace (2002, p.647) suggests "we are to understand the universal state as an entity with such-and-such mathematical description *which can be thought of as a collection of instantaneous worlds together with their Hilbert-space amplitudes, no matter that it may be decomposed into such a collection in many different ways*." (Original emphasis).

[21] One might suggest that when Everett worlds are represented according to the fundamental representation, it's not that the representation makes the target system exogenous but rather that the endogenous/exogenous distinction breaks down. Perhaps this is so, but for my purposes all I require is that the nature of the fundamental representation does not carry it with the notion that there is a particular demarcation of what constitutes an Everett world. I still think this point holds even if one's preferred view is that the endogenous/exogenous distinction breaks down in the fundamental representation.

representation. Thus according to the immanent representations of an Everett world, each Everett world carries with it (or has the potential to carry with it) an immanent representation. By definition of *immanent representation*, there is a one-to-one correspondence between the representation and each Everett world.

This one-to-one correspondence is unaffected by challenges of vagueness. If the object in question has indeterminate borders (an object such as a cloud, or an Everett world), but is represented immanently, then the representation simply incorporates such indeterminacy into its representation. So if a cloud has an indeterminate border, a cloud that is represented immanently includes this indeterminacy into its (determinate) representation. No matter the degree to which one precisifies a cloud, implicit in the immanent representation of that cloud is a determinate, higher-order demarcation of a cloud. In other words, the (higher-order) immanent representation of a cloud is such that the representation is determinate, even if the object it picks out is indeterminate (as viewed from another representational perspective). Again, this idea carries over to EQM: no matter the degree to which one precisifies an Everett world, implicit in the immanent representation of that world is a determinate, higher-order demarcation of a world. In other words, the (higher-order) immanent representation of an Everett world is such that the representation is determinate, even if the object it picks out is indeterminate (as viewed from another representational perspective).

There is also reason to think that the immanent representation carries conceptual priority; the concept is established *prior* to the immanent representation of it. In the case of an Everett world, one requires an Everett world concept in order to represent it immanently. Given the representer is part of the representation, the representer must be acquainted with the system it is representing in order to successfully represent that system immanently. This is the type of one-to-one correspondence implicit in the immanent representation of an Everett world.

If, on the other hand, an Everett world is represented as part of the structure picked out by the fundamental representation, there is no one-to-one correspondence that relates the Everett world to the mode of representation and no structurally determinate feature of the representation that implicitly picks out a particularly demarcated object. Implicit in the fundamental representation of an Everett world is *not* a determinate, higher-order demarcation of a world; the demarcation is derivative of the coarse-graining. This is a feature I think should be considered by any account which aims to explicate the indeterminacy of world number in EQM.

5.8 Realism

I've suggested that some authors endorse at least implicitly the claim that—to borrow Rayo's (2022, p.6) phrase—"there is a definite fact of the matter about how the world is" (or indeed, "what is really happening out there in the world" as Dizadji-Bahmani puts it). Pushing against this claim does not compel one towards antirealism (or even the related views acknowledged in §4.1). Rather, denying that there is a definite fact concerning how the world is can motivate a view which says there is reason to think (as hopefully illuminated by the analysis above) that the number of objects there are is inextricably linked to the representational resources we have available to us.[22] In other words, there is no sense to be made of a metaphysically significant demarcation of the world into constituents that is over and above how the world is represented.

Let us spell out the assumption in a little more detail. Recall Dizadji-Bahmani's (2015, p.278) suggestion that to compare the number of Everett worlds with the number of clouds in the sky is a "contentious slide from a metaphysical claim—claim about what is really happening out there in the world—to a worry about definitions." Such a statement appears to draw a clear distinction between the metaphysical, namely the so-called *objective* world of which there is a definite fact about, and the definitional, namely which structure our language actually picks out (however precisely) in the representation of particular concepts. On such a view, there appears to be a metaphysically privileged demarcation of the world—a metaphysically privileged "carving up" of the world—into constituents and it is these constituents which comprise the metaphysically privileged ontology. If there really is a definite fact concerning how the world is, and thus a metaphysically privileged demarcation of the world, then it presumably follows that the concept of an Everett world is well-defined according to the metaphysical fact about how the world really is.

It's not clear however that we can separate the question about what is (really) happening out there in the world from the resources we use to represent it. In the Everettian picture, we have seen (in §5.7) how the particular concept of an Everett world typically used in discussion is inextricably tied to the immanent representation; any system that represents an Everett world immanently is included within the representation and thus each Everett world carries with it (or has the potential to carry with it) an immanent representation. The apparent determinacy of the world around us ("this world"; "our world") is an artefact of this mode of representation.

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[22] Antirealism here is meant broadly as any view that relinquishes the metaphysical commitment to a mind-independent reality.

Recall Wilson's (2020) caveat that "it may in some sense be up to us what we mean by 'Everett world': but given any determination of what is to count as a world, it is not up to us how many such objects there are." The most illuminating piece of this proposal is, I think, the "determination of what is to count as a world". The problem here is that determining what is to count as a world is inextricably linked to the resources of each mode of representation. As suggested in §5.7, when we represent Everett worlds in accordance with the fundamental mode of representation, we do not encounter a feature of the sort presented by the immanent representation (namely, the fact that the system doing the representation is part of the representation). Everett worlds, when represented according to the fundamental mode, are in many ways analogous to the number of clouds in the sky since at this level of representation, the (hypothetical) system doing the representing is not part of the representation; the (hypothetical) system is exogenous. Thus one can introduce notions of indeterminacy since there is no obviously privileged demarcation of Everett worlds tied to the mode of representation. And since there is no metaphysically privileged demarcation of Everett worlds under this mode of representation, it's not obvious which criteria one should employ to count the number of worlds.

In light of the above explication, I hope the tension between references to "this world" or "the one and only Everett world that we ourselves occupy" and the indeterminacy of world number is relieved somewhat. To reiterate: I have argued that this tension is generated from illegitimately reifying one mode of representation in the context of the other. The immanent representation and the fundamental representation are two modes adopted in EQM to represent a single structure, but the superimposition of these two representations leads one to incorrectly conclude that features inherent in one mode of representation re-surface in the other mode of representation. In our context here, one illegitimately reifies features of the immanent representation that has no place at the level of the fundamental representation. The individuation of 'Everett world' that is tied to the immanent representation is lost when considering all Everett worlds according to the fundamental representation; when the two modes of representation are superimposed, we are led to believe that there is tension between the determinacy of the immanent representation ("this world"; "our world") and the indeterminacy of world number in EQM. However, this superimposition is flawed: once one realises that such determinacy is an artefact of the particular mode of representation, and that that determinacy has no place at the level of the fundamental representation, one will, I hope, realise that there is reason to doubt the force of this apparent tension.

Let us situate this view of EQM in light of more recent discussion concerning the status of metaphysical indeterminacy in quantum theory.[23] The thesis I propose here aims to be primarily diagnostic; it suggests how tension surrounding the indeterminacy of world number is weakened by considering particular modes of representation employed in discussions of EQM. There are of course metaphysical implications to consider, however: most pressingly, what is the metaphysical status of Everett worlds on such a view?

I think the physical anti-absolutism view ultimately gives weight to those who argue *for* metaphysical indeterminacy in EQM. Though for clarity, let us begin by exploring the ways in which physical anti-absolutism may motivate a deflationary reading of Everett worlds.

Given there is no privileged coarse-graining of the decoherence basis and Everett worlds are not defined at the level of the fundamental quantum state, one may wish to eliminate worlds entirely from one's view such that the number of worlds in EQM is (determinately) 0. And if the determinacy of Everett worlds is an artefact of the immanent mode of representation—a determinacy which prompts difficulties conceptualising the multiverse as a *collection* or *multitude* of worlds—then there may be good reason to eliminate Everett worlds from one's view entirely.

Since the view here says that the indeterminacy of world number results from illegitimately reifying features of one mode of representation in the context of another mode of representation, we have little reason to issue any ontological commitment to an Everett world inasmuch as their function is to provide a way to comprehend the fundamental quantum state. That is, now we have a better understanding of indeterminacy of world number, one quickly realises all we are left with—ontologically—is the fundamental quantum state. The idea that a coarse-grained description delivers many worlds, and a finer-grained description delivers many more, relies on the demarcation of a single Everett world in order to establish a higher or lower world count, but now we know the determinacy of "this world" or "our world" is an artefact of the immanent representation, one can relinquish their ontological commitment to Everett worlds and reserve their commitment to the fundamental quantum state. In other words, the structure to which locutions such as "this world" or "our world" pick out, it may be argued, give motivation to the ontological commitment to Everett worlds, but there is reason to reassess such ontological commitment given these locutions are an artefact of the mode of representation.

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[23] Notable (recent) contributions include J. Wilson (2013), Glick (2017), Wilson (2020), and Calosi and J. Wilson (2021;2022). Quantum indeterminacy is a broad and difficult topic; my aim is only to comment on the metaphysical status of Everett worlds as a consequence of the view presented here.

However, recall that a distinctive feature of the view presented here says: it's not clear that we can separate the question about what is (really) happening out there in the world from the resources we use to represent it. Thus for those who are convinced that there is a metaphysical fact which is over and above how we represent the world, there is good reason to be deflationary about Everett worlds. If there *is* a representation of the world which picks out structure that is metaphysically privileged then one can relinquish any ontological commitment to entities that do not appear in that representation. If on the other hand one is convinced that the notion of a metaphysically privileged ontology—*which is independent of our representational resources*—is incoherent, there is little reason to prioritise a metaphysical privileging of structure picked out by the fundamental representation over structure picked out by the immanent representation.

The fundamental representation and the immanent representation aren't competing, they are different representations of the same structure that each carry particular features specific to the mode of representation. Everett worlds are theoretical tools as much as the fundamental quantum state is a theoretical tool; if one accepts that the notion of a metaphysically privileged ontology—*which is independent of our representational resources*—is incoherent, then one must accept that both the fundamental representation and immanent representation pick out structure worthy of ontological commitment.

5.9 Framework

In the previous section I suggested that the number of objects there are is inextricably linked to the representational resources we have available to us. On this view, the contents of the world are attributed a particular type of open-endedness since given any set of e.g., events, objects or worlds, one can (via the arguments presented in chapters 3 and 4) use that set to generate more. As set out in Rayo (2022 §8), whilst it may be true—in its most strict and literal sense—that there are entities (such as electrons, hydrogen atoms or Everett worlds), the particular descriptions we use to identify the relevant feature of the world have no intrinsic metaphysical significance; there is no single, privileged description we attribute to those features of the world. The facts we attribute those descriptions to can be described using many different, entirely separate sets of distinctions.

In the context of world number in EQM, the nature of an Everett world cannot be disentangled from the representational resources used to describe it. As such, the structure we pick out when representing an Everett world immanently is specific to that mode of representation and is not something that can be implemented in the context of another mode of representation, namely the fundamental representation in which all worlds come into view. To paraphrase Rayo (2022, p.28), there is nothing about reality "*as it is in itself*" that settles whether the distinction between there being an Everett world and there not being an Everett world is "objectively correct".

This concludes my presentation of EQM—for now. Before returning to the topic in the final chapter, I turn my attention to totality and *nothingness*.

6. Totality and Nothingness

We saw in chapter 3 instances in which representations we appeal to in describing totality aren't well-defined by physics. What I intend to do in this section is a concise analysis of *nothingness*[1], which bears comparable properties to the notion of totality. Identifying similar and contrasting features in both *totality* and *nothingness* may help point towards fruitful research projects in the physics and metaphysics of totality.

6.1 The (Meta)Physics of Nothingness

In the recent past, discussion within the physics literature has conflated the concept of nothingness with the properties of a quantum-mechanical vacuum (e.g., Tryon 1973; Vilenkin 1982; Aitchison 1985; Krauss 2012).[2] Exploring the properties of a quantum-mechanical vacuum is a valuable task in itself, but I have concerns with the more metaphysical, perhaps conceptual reading of nothingness, namely the absence of *all things* (including quantum mechanical vacuums). It may of course turn out that our pre-theoretic conceptualisation of nothingness is incorrect; perhaps the universe has always and will always exist, in which case something like a quantum vacuum may be the best physical candidate for a description of 'nothingness'. In other words, if it's impossible for the universe to cease (or to have ceased) to exist, there can be no (lack of) physical state which would satisfy our pre-theoretic notion of nothingness.[3] In modal terms, there is no possible world in which there is nothing. If we find good reason to believe such a thesis, this would be a strong case to revise our metaphysics, which typically takes for granted that nothingness is what remains when everything is removed, and that everything removed is a possibility. For now, this is still an open question, and even if physics tells us that the universe is eternal towards the past and the future, there are important lessons one can

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[1] Philosophers distinguish between 'nothing' as a quantifier and 'nothing' as a noun, which I call 'nothingness' (e.g., Priest 2021 §2). For example, "nihil" is a quantifier, and "nihilo" is a noun in the dictum *ex nihilo nihil fit* ("out of nothing, nothing comes").

[2] See also Albert's (2012) review of Krauss's (2012) book, which directly assesses the gap between the metaphysics and physics of nothingness that I discuss in this chapter.

[3] This isn't to deny the notion of nothingness; it rather raises a question of whether the concept of nothingness should be updated in light of knowledge concerning the physical universe.

draw from the difficulties we face in trying to conceptualise nothingness as the absence of everything.

In recent metaphysics, the problem of nothingness is often considered within a framework of Meinongianism (see Priest 2014a, 2014b), which includes the following axiom: everything toward which an intentional state or activity can be directed is assigned the status of an object. This is the primary source of paradox in conceptualising nothingness: since nothingness is the absence of everything, in what sense are we to think of nothingness as a thing? It's not clear how the absence of everything can reach the status of an object; perhaps if it were an object then it wouldn't be the absence of everything. On the other hand, since this section considers nothingness, and considering you are (hopefully) thinking about nothingness now, it follows (at least within the Meinongianism framework) that nothingness is an object. Nothingness is contradictory—it is simultaneously an object and not an object.[4]

The formation of the inquiry posits nothingness as having the very property it is devoid of. As Heidegger (1977, p.98f) puts it, "the question deprives itself of its own object". I think it's helpful here to consider the contradiction from the view of physics. The problem, in physical terms, lies with the fact that there is no way to remove the system from the domain it intends to describe. The domain of nothingness is totality, it is defined by the absence of *everything* and requires that *there are no more* objects, *no more* facts (however construed) to be removed. If a system is embedded within the domain of totality, which all physical systems are, and it attempts to represent nothingness, there will be interference[5] between the system and that which it represents. Totality (and thus nothingness) cannot be stabilized independently of the questions we put to it since the system doing the representing is included within the representation. The contradiction occurs because nothingness is represented within the domain to be emptied of all facts.

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[4] Graham Priest (2014b; 2021) simply accepts the contradiction, suggesting that nothingness is the mereological sum of everything that is contained within the empty set. Nothingness is that which arises when you fuse the members of the empty set, namely the fusion of no things. This may still seem puzzling, however. How can there be a fusion if there are no objects in the empty set to be fused? Priest employs a particular notion of *coherence* to determine the fusion of a set of objects. For the members of a set to have fusion, the objects must *cohere* in some way: the parts of my body have coherence, but it's not obvious that a set comprising for example, my house keys, the Royal Academy of Arts, and Neptune does. In what sense should we understand coherence within an empty set? Priest suggests the objection is irrelevant since the empty set has no members that fail to cohere, or to put it slightly differently, all members of the empty set cohere because there aren't any.

[5] Of the type detailed in §3.7.

6.2 The Physics of Nothingness

A recurrent theme of physical anti-absolutism, and one I intend to revisit here, is to consider the intersection between metaphysics and physics. Given recent discoveries in vacuum physics, the physics of nothingness is an interesting case: physicists have drawn the concept of nothingness into discussions of vacuum physics (e.g., Wilczek 1980; Krauss 2012), with little consideration for the metaphysics of nothingness. In a similar vein, metaphysicians have predominantly considered nothingness as the absence of everything with little input from contemporary physics (e.g., Priest 2014a, 2014b).

One simple and obvious thought is that there are two different concepts at play here. On the one hand, a false-vacuum state is a physical state that requires a quantum wavefunction; on the other, nothingness is the absence of everything. And so one may think that presenting a view of nothingness by appealing solely to arguments concerning the physics of vacuum states misses the point. A sharper way to present a view of nothingness in light of contemporary physics (as some do, e.g., Carroll 2021) is simply to acknowledge the distinction between the conceptual and the physical. As we have seen, the metaphysician runs into a contradiction if she tries to attribute nothingness with the status of an object that affords inquiry. A contradiction arises since the representation always falls under the domain it represents as having no facts, namely totality. As alluded to earlier however, what if we take seriously the idea that the laws of physics are not compatible with an absence of everything? If this is the case, there may be motivation to update our pre-theoretic concept of nothingness to reflect its status according to contemporary physics.

If the theory that best describes the world is one in which the dynamics are given by the Schrödinger equation or some theoretical equivalent, then almost all[6] states evolve eternally towards the past and the future, and the universe has no beginning nor end of time (something like the Big Bang is still possible, it just wouldn't carry with it the status of a true physical singularity as it would under General Relativity, or represent the initial moment of the universe). There is a crucial assumption here, however: in specifying the Hilbert space and Hamiltonian, the Schrödinger equation applies to any *isolated* quantum system. To suggest that almost all states evolve eternally towards the past and the future, and that (therefore) the universe has no beginning nor end of time is to identify the universe as an isolated system. If the universe isn't

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[6] The exceptions are states with zero energy. See Carroll 2021 §3.

an isolated system, it becomes more difficult to draw conclusions concerning the eternal evolution of states towards the past or future.

In chapter 2 we saw the motivation for thinking that the notion of an absolutely general domain is incoherent; a simple Cantorian argument tells us that there can be no set of all facts. Moreover, in chapter 3 we saw how representations of physical reality *as a whole* may not have well-defined physical descriptions under Newtonian mechanics, relativistic physics and quantum mechanics. If one is willing to accept these arguments, this perhaps motivates the thought that there are difficulties inherent in the very idea of nothingness, if construed as the absence of everything. If there is no sense to the notion of absolutely everything, and if by any given collection of objects, I'm always in a position to characterize more, then it may be argued that there is *also* no sense to the idea of nothingness—if construed as the absence of everything—since one can never coherently speak of the domain they hope to empty of all objects, namely the absolutely general domain. Perhaps there can be no *absence* of absolutely everything if there is no sense to be made of absolutely everything; the universe can never be held fixed in order to fix what it is absent of.

We therefore have two routes available which may create difficulties for a view that proposes nothingness as the absence of everything. On the one hand, if the Schrödinger equation or some theoretical equivalent correctly describes the universe as an isolated system then almost all states evolve eternally towards the past and the future, and the universe has no beginning nor end of time. On the other hand, if the universe is *not* an isolated system, then—in view of *physical anti-absolutism*—nothingness is unattainable since one can never coherently speak of the domain they hope to empty of all objects. To be clear, I actually think that the arguments of the physical anti-absolutist apply just as well to a universe which is isolated but prima facie, they appear even more persuasive to a universe that isn't isolated—perhaps best represented as a non-unitarily evolving density operator and best characterized as open-ended or incomplete. This is not to suggest that there is no place for the metaphysical pursuit of nothingness as the absence of everything but merely to note the tension it has with the physical domain.

There is further work to be done here which explores the relationship between the physical, the conceptual, and nothingness. For example, does the absence of all physical states still leave room for the existence of the non-physical? If one is Platonist about numbers, for example, does their existence survive the absence of all physical states? Whilst I take these questions to be particularly interesting, I defer discussion of these questions to my own future research projects and encourage others to do the same. I do hope however that this (brief) chapter has succeeded, if even only partially, to provide a novel take on an old problem, connecting areas of metaphysics and physics with a view to further illuminate the notion of nothingness. I have suggested that nothingness is an interesting case in the present context since it is typically defined in terms of totalities (the absence of everything). I have also given thought to its place within physics and suggested reasons why the notion of nothingness is unattainable to the anti-absolutist.

In the final chapter, I propose that those who endorse the Parfittian fission analogy (however implicitly) in discussions of EQM end up presupposing a privileged metaphysical description—but this is a mistake. In identifying a number of disanalogies between Everettian branching and Parfittian fission, I suggest that Everettians are doing themselves a disservice when they seek to employ arguments by analogy from fission cases.

7. Everettian Quantum Mechanics and the Ghost of Fission

This chapter is a digression—of sorts. Given that discussion of totality in the context of Everett's theory has drawn out some interesting metaphysical consequences from the physics, then I suggest there is reason to reassess a metaphysical picture which is frequently associated with the theory. A particularly influential way of formulating foundational or conceptual questions in Everettian discussion is by appeal to the Parfittian (1984) fission analogy, and although there has been in my view a welcome shift away from explicit use of the analogy in some more recent discussion, I will argue that its effects still pervade much of the contemporary literature.

Whilst Parfittian fission arguments are themselves interesting philosophical arguments, understanding EQM by analogy with fission enforces a particular metaphysical approach to EQM that limits its relevance to the philosophical questions that I hope to have raised. My suggestion is that the fission analogy encourages a reading of EQM through the lens of reality as we know it, undesirably importing features of the ordinary world into a very different physical setting; it encourages one to export conceptual machinery relevant to our own experience into a domain which isn't constrained by such features. Whilst the fission analogy may aid our imagination, it does so at a cost of obscuring interesting philosophical content of Everett's theory, content that is relevant to interesting ways of thinking about totality. Contrary to the analogy being introduced as a way to illuminate conceptual issues in EQM, I suggest that the analogy distracts away from the (potentially more perspicuous) metaphysics that we arrive at if we take the physics seriously. If arguments by analogy with fission cases constrain the metaphysics in a way that is not supported by the physics, such analogies should be abandoned.

In applying the arguments of Rayo (2019, 2022) to EQM (chapter 5), I suggested that the particular descriptions we use to identify features of reality have no metaphysical significance. The features we attribute descriptions to can be described using many different, entirely separate sets of distinctions and thus there is nothing about the world "*as it is in itself*" (Rayo 2022, p.28) that settles whether a particular fact holds; there is no single, privileged description that will tell us whether a distinction is *objectively* the case. I propose that those who endorse the Parfittian fission analogy (however implicitly) assume that there is a privileged metaphysical description, but this is a mistake; such claims are coherent when applied to fission cases but do not carry over to EQM, thus motivating a reading of Everett that is hostage to a misapprehended metaphysics. I'll begin with the relevant setup of both EQM and fission cases (§7.1) before discussing the disanalogies between them (§7.3). In the final half of the chapter (§7.4-§7.6), I apply the disanalogies to the Everettian probability problem.

7.1 Everettian Quantum Mechanics and Fission Cases

Parfittian (1984) arguments from 'fission' cases are often utilized in discussions of Everettian quantum mechanics in an attempt to illuminate details of familiar accounts in which an agent 'splits' or 'branches'. Whilst this analogy is often seen as a vivid but innocuous depiction of Everett's theory, I will argue that it is in fact a poisoned chalice. Everettians are doing themselves a disservice when they seek to employ arguments by analogy from fission cases.

Debates concerning the foundations of EQM over the past 20 or so years, spearheaded by the 'Oxford Everettians' (David Deutsch; Hilary Greaves; Simon Saunders; David Wallace) abundantly reference late 20th century personal identity literature that attempts to make sense of scenarios in which agents undergo brain transplants or are subject to teleportation devices. In contrast to Wilkes' (1988) suggestion that technological impossibilities render solutions to these scenarios unnecessary, Greaves (2004 pp. 428-429) claims "such a comfortable reply is not available to the Everettian—far from being impossible, he believes, fission is *inevitable*!"; similarly, Heather Demarest (2016 p.567) concludes "if this theory of (Everettian) quantum mechanics is right, then fission actually occurs (and actually occurs all the time!)—it is no longer a purely hypothetical thought experiment." Elsewhere, Wallace (2003a p.101) refers to an observer surviving as two copies following a quantum mechanical measurement as "closely analogous to the cases of personal fission considered by Parfit", (endorsing Saunders' 1998 account in the process), and with similar intent, Papineau (1995 p.245) describes the Parfittian discussion of personal survival as providing a "useful analogy" to an observer who undergoes Everettian branching. Talk in this vein has become a familiar backdrop and guiding principle that continues to pervade even more recent explorations concerning the foundations of EQM: Sebens and Carroll[1] (2018) and McQueen and Vaidman (2019) both implicitly endorse fission-style structures (in addition to e.g., Lewis 2007, Meacham 2010, Price 2010). With this in mind, let us first turn to the details of EQM and secondly to the *fission case*—a term I will use to refer to Parfittian fission scenarios.

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[1] Whilst Sebens and Carroll suggest their strategy is not restricted to a particular metaphysics (see their footnote 4), I will argue in §7.4 that their account is weakened by being implicitly aligned with the fission setup.

Consistent with the rest of the thesis, I will be focusing on the so-called decoherence-based EQM, central to the arguments of Deutsch, Greaves, Saunders and Wallace. For ease of presentation let us briefly revisit the relevant details. When decoherence occurs, quantum mechanical systems develop a 'natural' branching structure[2]: a system's environment is continually entangled with the system so that interference is suppressed between terms selected by the preferred basis. Relative to a particular basis, a state evolves from a basis vector to a superposition of basis vectors. Those basis vectors subsequently evolve into a superposition of different basis vectors and no significant interference occurs between superpositions. This gives us the sense of multiplicity most frequently associated with the Everett interpretation: after a quantum mechanical measurement, there are multiple Everett worlds each corresponding to a measurement outcome.

An agent about to make a quantum measurement can then ask the following: how can it make sense to isolate a single outcome as the *actual* result, given there are branches in her future where each measurement result is displayed on the measurement apparatus *and a successor of hers is there to observe it*? Whereas the states associated with unactualized possibilities of quantum measurements remain unactualized on other interpretations of quantum mechanics, for the Everettian these states are now actual outcomes according to each Everett world's own inhabitants.

Given these agent-splitting implications, philosophical arguments from Parfittian fission cases come directly in to view.[3] Thought experiments concerning an agent's evolution into multiple copies have come in many forms[4]. Broadly speaking, scenarios can be grouped under 'duplication' or 'division'. 'Duplication' proposes to identify and duplicate each and every particle comprising an (unconscious) agent and assemble an exact agent-copy[5]. 'Division' splits and transplants the agent into new compatible structures. One of the more common examples is a hemispherectomy: a brain is split into two halves and successfully transplanted into two new bodies (either human or synthetic), which I will adopt for the rest of the presentation.[6] Standardly, there are three available options for the agent about to undergo fission, namely i) expect

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[2] See e.g., Wallace (2010a; 2012 Ch.3)

[3] In light of the overlap/divergence distinction, it's an open question whether any 'splitting' happens at all.

[4] E.g., Lewis (1976), Noonan (2003), Perry (1972)

[5] A variant of this option is to produce two (or moiviel agent-copies and terminate the original.

[6] Distinguishing between these two methods (and their associated variants) has borne philosophical fruit (for example, a duplication scenario may be said to involve deviant causal chains thus questioning the integrity of the inherited memories), however, whilst there is a genuine question about which form most closely resembles the metaphysics of EQM, I take the arguments I present to remain unaffected by the distinction. I therefore set these disputes aside.

nothing; ii) expect to become both successors; iii) expect to become either successor. One's account of personal identity in branching situations will dictate the strength of each answer but we typically see discussions (e.g., P. Lewis 2007) reference the following three strands.

Parfit's (1984) account identifies an agent as a three-dimensional object that persists over time. Presuming a pre-fission agent branches into two post-fission successors, a pre-fission agent is psychologically continuous but not identical to either of the post-fission successors since psychological continuity is not a transitive relation.

The Lewisian account (Lewis 1976) identifies an agent as a four-dimensional object (a spacetime "worm"). There are two agents present before and after fission, the pre-fission agents coincide; the post-fission agents diverge.

Sider (1996) identifies an agent as a momentary stage of a four-dimensional object. The stages are united over time, but the aggregated four-dimensional object is not an agent. There is one pre-fission agent and two post-fission successors. The agents are related in the following sense: the pre-fission agent is not identical with either of the post-fission successors, but the pre-fission agent bears the relation *will be* to the post-fission successors. Let us now consider the analogy between EQM and fission cases.

7.2 The Analogy

In chapter 3, I discussed the analogy between EQM and Parfittian fission cases, which have predominantly been brought into EQM discussion to help illuminate problems concerning probability. Recall the following: the *incoherence problem* says: given that all possible outcomes of experiments are realised in some post-measurement branch, how can we speak of probabilities at all? The quantitative problem asks why should these probabilities be given by the Born rule (even if it's coherent to assign probabilities to the outcomes of measurements)? Finally, the *epistemic problem* asks how our empirical evidence is justified according to EQM. The foundational metaphysics of Parfittian fission scenarios have often underpinned attempts to address these problems. I will adopt this categorization of problems when analysing applications of the analogy in §7.4-§7.6.

Saunders (1998 p.385)—though no longer endorsing this position[7]—suggests that Everettians can rationally adopt an attitude of what has subsequently been called *subjective*

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[7] Saunders' current view is explicated in Saunders (2010a, 2010b), which will be addressed in the forthcoming sections.

uncertainty regarding future branching. Proceeding by analogy with fission, Saunders aims to demonstrate that the question, "which future self should I expect to become?" is subjectively indeterministic. A pre-fission agent "should expect to become one or the other with equal likelihood" given there is no legitimate reason to favour one successor over the other. For Saunders, the analogy is sufficient to be carried over to EQM: "the similarities between this and the quantum mechanical case are evident."

Wallace (2003b, 2006) sets out to prove the decision-theoretic link between objective probabilities and rational action.[8] Endorsing Saunders' fission thought experiment, Wallace argues that objective probabilities are synonymous with Everettian branch weights, which quantifies alternative possibilities, and thus subjective uncertainty.[9]

Greaves (2004, 2007) denies that objective probability makes sense in Everett's theory. Assigning objective probabilities to branch weights, according to Greaves, does not make branches with a high Born rule weight any more likely to occur—to the contrary, all outcomes occur. An agent does however (in contrast to Parfittian fission) have a *caring measure* over her successors in EQM, and so can rationally assign differential care values for future branches—a view she calls the *fission-based interpretation*.

Greaves rejects subjective uncertainty, and instead proposes an argument for *subjective certainty* (2004, §4.1.3). The question "what will the agent see?", Greaves argues, is badly posed. Rather, her proposal is that the pre-branching agent "should (with certainty) expect to see spin up" and the pre-branching agent "should (with certainty) expect to see spin down", concluding, "Not that she_1 should expect to see *both*: she_1 should expect to see *each*." (Greaves 2004 p.441). Despite there being no uncertainty, Greaves suggests it is still rational for an agent to differentially attribute a measure of care over her future selves.

Structural features of the fission analogy seem to bear weight in the above arguments. Employing the analogy as a means to disentangle the metaphysics of EQM presupposes an analogous metaphysical structure. If there is reason to believe that the fission case analogy is responsible for the conceptual foundations of arguments concerning Everettian branching—and it turns out that the analogy is more limited than its exponents have assumed—then much

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[8] Following pioneering work by Deutsch (1999).

[9] Wallace (2003b, p.417) suggests: "In my view, the most promising approach is Saunders' 'subjective uncertainty' theory of branching: Saunders argues (via the analogy with Parfittian fission) that an agent awaiting branching should regard it as subjectively indeterministic. That is, he should expect to become one future copy or another but not both, and he should be uncertain as to which he will become." Moreover, "The idea of subjective uncertainty…was originally proposed by Saunders (1998), who argues for the SU viewpoint by means of an ingenious intuition pump. His argument proceeds by analogy with "classical splitting", such as that which would result from a Star Trek matter transporter or an operation in which my brain is split in two." (Wallace 2006, p.664).

of the discussion of the probability problem has been predicated on a problematic analogy and the debate has suffered as a result. The following section will illuminate some difficulties in transposing the fission case to Everett's theory.

7.3 The Disanalogies

There are numerous disanalogies between EQM and fission cases but here are those I take to be the most relevant.

Diverging/Overlapping

Recall from chapter 3 that the diverging/overlap distinction in EQM is the following: if the entities appearing in two different consistent histories—mathematically represented by a particular projection operator—are considered numerically identical, we are given overlapping Everett worlds. If on the other hand, those entities are (numerically distinct) qualitative duplicates, we are given diverging Everett worlds.[10] Either picture is an available metaphysical option for the Everettian; the formalism remains the same but can be interpreted either way. Figure 4 (reprinted below for ease of presentation) contains illustrations often used to schematically represent the respective Everettian metaphysical pictures, which should help clarify why overlap (and not divergence) gives rise to notions of splitting or branching.

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[10] To reiterate my earlier statement (§3.5): For those sceptical of divergence, Saunders (2010b) and Wilson (2011, 2020) suggest divergence is not only viable but a preferred metaphysical reading of EQM. Sebens and Carroll (2018 fn.4) acknowledge their strategy can be implemented on either overlap or divergence. Despite questioning diverging Everett worlds, Tappenden (2019b, §5) recognises its appeal, devoting a whole section to the view. The view is considered in similar detail in Tappenden 2019a. Gomes (2018, p.703) may also be read as proposing a diverging worlds approach (despite not adopting the terminology): "To be more precise, nothing is splitting, all the individual copies of the system already exist in timeless *Q*."

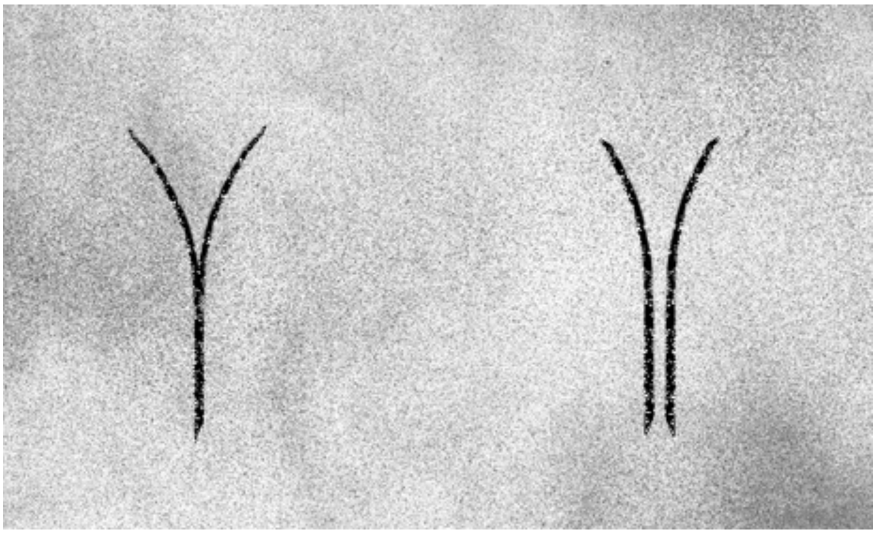

Figure 4 (reprinted). Overlap (left); Divergence (right).

This distinction simply isn't available in the fission case. By its very nature, the fission case makes no room for a diverging interpretation; employing the fission case as a framework to discuss conceptual features of EQM only makes contact with the overlapping metaphysical picture.[11]

One might suggest that Everett worlds can only overlap if worlds are identified with their *histories* (following Lewisian worm theory), but if we employ the Siderian stage-theoretic view of persistence then worlds are identified with *stages* of their histories; these stages do not themselves overlap other stages. Tappenden (2008; 2011; 2017; 2019a) is perhaps the most notable advocate[12] of stage theoretic views of persistence in discussions of EQM following Saunders' (1998) appeal to Lewisian worm theory, but the details of theories of persistence are actually somewhat independent of this chapter's aims. *Prima facie*, the metaphysics of persistence and the ontology of Everett worlds seem like separable questions and as such, this chapter proceeds by treating them separately.

I concede that, under the assumption that stage theory is correct then agents and indeed worlds are to be identified with stages. But nonetheless one may still ask questions about the mereological sums of multiple stages and the mereological relations they stand in. In other

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[11] Some (e.g., Wallace 2012) may question whether there's a substantive distinction between overlap and divergence, but that only helps my case since the proposals I call into question assume that there is in fact a substantive distinction and that overlap is correct. As such, I will set aside scepticism about the distinction, interesting though it may be, to address the strongest views incorporating the fission analogy.

[12] Greaves (2004) introduces a notion of stages but without reference to Sider.

words, we can always reconstruct the overlap/divergence distinction by considering the aggregated sequence of stages. This chapter explores the role of the Parfittian fission analogy in discussions of foundational questions in EQM; even if authors point to a view in which worlds are identified with stages of their histories, such a view doesn't escape the influence of thinking within a Parfittian fission framework. It would be an interesting project to scrutinize the various theories of persistence and explore their consequences for Everett-world ontology, but this would require a much longer treatment and is not something I have space to address in detail here.

Spacetime Connectedness

In consideration of how fission cases are typically presented one can be confident in identifying a disanalogy between the structural features that connect regions of spacetime occupied by post-fission successors and the structural features that connect regions occupied by post-measurement successors in Everett's theory.

Spacetime structure advocated in Parfittian fission cases has the following property: the region of space occupied by the two post-fission successors allows for causal and informational relations.[13] On the other hand, the decoherence-based EQM theory I have in mind proposes post-branching worlds as distinct, which can be described by properties concerning the wavefunction's amplitude in distinct regions of configuration space. On either metaphysical view, namely overlap or divergence, successors inhabit distinct Everett worlds following a quantum measurement. Thus in the fission case, post-fission successors inhabit regions of spacetime that permit causal relations, whilst in EQM post-branch successors inhabit distinct worlds.[14]

The spacetime features that permit causal relations between the successors of a fission case do not hold between the post-measurement successors in EQM.

Branch Number

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[13] It may be objected that since the fission case is a thought experiment, its spacetime structure is unspecified, but this causal condition is met by, for example, a standard (Minkowski) spacetime. In any case, the Parfittian fission case is set up so the two post-fission successors can interact; in EQM, post-measurement successors inhabit distinct worlds.

[14] Moreover, it may be argued that there is little reason to assume that all Everett worlds are spatiotemporal and so the very notion of spacetime may lack the necessary precision to demarcate worlds (see Wilson 2020, in particular section 1.6 and Ch.2). My emphasis here subsequently resides with causal isolation between post-measurement successors rather than spatiotemporal isolation.

The approximate symmetry of the brain produces a very natural bifurcation for Parfittian fission. The fission procedure generates a determinate number of successors, namely two—one for each half of the brain.

In contrast, there is no discrete branching structure available to the Everettian. Everettian branching follows from the absence of interference but there is no precise point at which this absence occurs (see §3.5). The branching structure emerges depending on how one chooses the discretization of configuration space, and there is no choice that delivers a natural 'grain'; branches may be decomposed at timescales corresponding to more coarse-grained or more fine-grained descriptions. Thus, in contrast to the fission case, we can describe branch number in EQM as indeterminate.[15]

Alternative Possibilities

Perhaps the most suitable candidate to attach the idea of an alternative possibility in EQM is the squared amplitude assigned to each branch of the wavefunction. As touched upon in §7.2, whilst such values are often presented as probabilities, it's contested whether they can be attributed the status of probability at all (Papineau 1996, Saunders 1998, Vaidman 1998, Greaves 2004, Wilson 2013). Putting the nature of these probabilities aside, there is still an available measure over which one can assign values to the space of outcomes following the measurement of a quantum system. These *physical* probabilities aren't available to an agent looking to assign values to the possible outcomes of a Parfittian fission case. What could it mean for each successor in the Parfittian fission scenario to be assigned an objective probability? The fission scenario has no space for talk of this kind.

Energy and Mass Conservation

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[15] Although there is consensus, the question "how many branches?" has prompted a number of responses in the literature (see §3.5). The variation in responses is telling of the question's difficulty. But for my purposes, a disanalogy still remains; I grant that indeterminacy may be the wrong concept to attribute to branch number (although it seems quite close), but whatever the correct concept is, is not analogous to the determinacy of successors in the fission case.

Relatedly, Tappenden (2019a) proposes that a quantum superposition is a superposition of elements in the set-theoretic sense. On Tappenden's view, if there is an element in every Everett world, an object is constituted by the *set* of those elements. He writes: "In any sort of situation where there are multiple doppelgangers in isomorphic environments but where the quantity of 'worlds' may be any number N, the mind of a subject is instanced by a set of N-brain-like objects". The coherence of this account seems reasonably committed to a determinate number of worlds. I by no means suggest that the Parfittian fission analogy played any explicit role in the formulation of Tappenden's proposal but it is at least relevant to our discussion here that a feature incoherent in EQM but coherent in the framework of Parfittian fission bears significant weight in Tappenden's account.

Conceding that the fission case is a thought experiment, *prima facie* a hemispherectomy requires an energy input. That is, a source of energy is necessary for brains to be split.

The situation is different in EQM. For reasons outside the scope of this thesis, the energy of the universe is typically given by an expectation value of an energy operator relative to that particular state (see Carroll and Lodman 2021 §2 for details). And as the wavefunction evolves over time, we can interpret a measurement of energy from the transition probabilities given by the branch amplitude. For an agent to branch after a quantum measurement, there is no energy input (as per the fission case) that 'fuels' the process directly. The wavefunction has simply evolved over time, and the total energy of the isolated system has also evolved in accordance with the individual branches. The value most likely to occur (its expectation value) is therefore the most suitable candidate to describe the energy of each branch, as measuring the energy of a particular system results in a peak in the wavefunction of the value obtained. There is no energy input required to 'create new universes', and so ideas of a universe splitting and giving rise to either double or half the energy/mass are thus quickly dispelled.[16]

There is also a link between energy and mass conservation on the one hand, and alternative possibilities on the other that may help further illuminate why the situation is so different in EQM. If one admits of alternative possibilities in Everett, the objective probabilities are doing some work in guiding these alternative possibilities. As I discussed earlier, the distinct objective probabilistic outcomes can be traced to features of reality represented by squared moduli of wavefunction amplitudes. The Everettian can weight alternative futures differentially when making decisions as she is committed to weighing these futures according to the squared amplitudes.

Since the energy of each universe is given as a weighted average of the total energy of all branches, the branch weights used to differentially weight alternative possibilities are also guides to the energy and mass associated with each branch. There is common ground to the possibility of each outcome and its respective mass and energy.

Acknowledging this structure hopefully clarifies how little room there is in the fission case for analogous concepts. What we mean by "alternative possibilities" and by the "mass and

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[16] Some still may doubt we can coherently talk about energy and mass in a thought experiment context, but I think this is misguided. The disanalogy arises from the following: however we wish to construct the Parfittian fission experiment, it will always utilize energy in a way that is disanalogous to how we think about energy in EQM. Our intuitions that reside with fissioning objects (e.g., the mass of the pre-fission object equalling the sum of the post-fission objects' mass) are not carried over to the Everettian context.

energy of the universe" in EQM stems directly from the structure of the theory that generates objective quantum probabilities. But there is no comparable structure in the fission case that will help provide an insight into these mechanisms proposed in Everett's theory. The way in which the disanalogies are related I think provides a deeper insight into why they arise in the first place. Everettian alternative possibilities and Everettian energy conservation differ so much from ostensibly equivalent concepts in the fission scenario because of their emergence from the structure of Everett's theory, a structure that connects them in a way unavailable in the fission case.

This concludes discussion of disanalogies between fission and Everettian branching. In what follows, I suggest reasons why the above disanalogies impact all three pillars of the Everettian probability problem.

7.4 Incoherence Problem

Recall the incoherence problem: given that all possible outcomes of experiments are realised in some post-measurement branch, how can we speak of probabilities at all?

Saunders and Wallace (2008) advocate a semantics for branching worlds in an Everettian multiverse. The idea is the following: they identify truth values with sentences at particular branches, and utterances as a pairing of the uttered sentence with a particular branch. If there are multiple branches, there are multiple distinct utterances. An utterance of 'I will survive' we typically expect to refer to one person, and for that person to be located at some particular branch. The authors wish to extend the nature of the term 'I', claiming ignorance about the crucial properties that determine which branch I am in fact located. Such self-locating ignorance purportedly solves the incoherence problem.

The salient feature relevant to my proposal is that Saunders and Wallace aim for their account to be metaphysically agnostic, insisting their project does not identify an appropriate metaphysics to underscore their theory. They make this explicit in their introduction (2008 p.294):

> It will be no surprise if the semantics we are proposing is contested on metaphysical grounds—say on the grounds of a metaphysical theory of reference, or a metaphysics of time, or of personal identity, or of modality. But to this our reply is that we are not proposing a metaphysical theory, but a manual of translation, in something like Quine's sense: the standard of correctness is set by fluency

> of discourse and the principle of charity, not by metaphysical principles; by its serviceability to our best physical theory.[17]

If this is the intention, Saunders and Wallace's setup (2008 §2.1) titled, 'Personal fission' is a distracting feature of their proposal. Proposing a metaphysically agnostic theory of branching is a difficult task in itself but implementing discussions of fission cases would seem to encumber rather than facilitate a proposal of this sort. Talk of fission cases within an Everettian setting naturally suggests metaphors of splitting, and thus is often associated with the overlapping metaphysical picture; contrary to Saunders and Wallace's intentions, this is precisely how Tappenden (2008) reads their proposal.

Tappenden suggests that Saunders and Wallace make no attempt to provide a "mechanism"[18] by which words (such as 'I') succeed in referring to the intended object. If we suppose an experimenter measures the spin of an electron along some fixed axis, then on Tappenden's view, there is no justification for how either of the two (purported) utterers can indexically refer to themselves prior to branching. The utterance has to be a *single* utterance as there is no fact that distinguishes the experimenter who will observe spin-up from the experimenter who will observe spin-down prior to measurement, thus the utterance is uttered by a person-stage common to both the person who will observe spin-up and the person who will observe spin-down.

These are difficult issues made no easier, I think, by an imprecise and distracting concept of branching. Tappenden reads Saunders and Wallace as endorsing a metaphysical picture associated with Parfittian fission (personal overlap). It then appears hopeful that these are concerns irrelevant to Saunders and Wallace's account. I grant that their account *works* by providing the intended serviceability, but it is not devoid of philosophically salient metaphysics—and it is here where the problems lie.[19]

Before discussing Tappenden's objection in the context of divergence, let me first introduce Tappenden's case to illustrate an example in which there *is* a mechanism by which an utterer secures an indexical reference. Tappenden imagines a *non-branching* world; perhaps, for

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[17] I take their notion of "serviceability" to mean something like the following. Their account makes explicit that there are no metaphysical truths about everyday words such as "person" or "I", beyond "those that are fixed by observable linguistic usage" (2008 p.302). Moreover, they do not accept that metaphysical principles can determine a *correct* semantics. The utmost an account can offer is a semantics that provides a simple, coherent and consistent way to navigate a branching universe. As I understand it, serviceability follows from satisfying these criteria.

[18] Tappenden (2008, p.309).

[19] Assessing the available metaphysical pictures for Saunders and Wallace's account has already surfaced in the literature. Alastair Wilson (2011) provides an evaluation of the metaphysical frameworks available to the authors if they were to drop their attempt at metaphysical agnosticism, concluding that the most appropriate framework is one which posits (non-overlapping) diverging worlds.

example, a single world under a dynamical collapse model of quantum mechanics. An inhabitant of this world, on Tappenden's (2008), p.310 view, can point at herself, saying 'this is my body', in which her use of 'this' is enough to secure a reference to the body in question. The reference "picks out a unique world-tube referent".

But similarly, if EQM is understood to be a theory proposing diverging worlds, then each utterance is vocalized by a single continuant inhabiting a single Everettian branch and there is also a mechanism by which one can associate the utterance with a single world-bound utterer. Tappenden's objection, namely that Saunders and Wallace's account fails to secure a mechanism by which words such as 'I' or 'this' succeed in referring to the intended object, fails to gain traction on a view such as divergence.[20]

Saunders and Wallace aim to be metaphysically agnostic, but the metaphysics is pivotal to the coherence of their account. If Saunders and Wallace do not wish to engage in the metaphysics, it would seem distracting to give a discussion of Parfittian fission cases in which an explicit metaphysical framework is established. Insisting on metaphysical agnosticism neglects philosophical ideas pertinent to the structure of Everettian branching. In fact, much of the debate between Saunders and Wallace and Tappenden has been driven by tension generated from the nature and conceptual difficulties of overlapping worlds in which—in light of Parfittian fission—one is urged to reconsider the status of a pre-measurement agent, the status of post-measurement successors, and the relations between them.[21] In the final note of the debate, Tappenden (2010, p.1) even acknowledges "…in their reply…they make it clear that they do not wish to invoke overlap of persons after all. That makes it mysterious why they defended their interpretation of personal overlap in the first place and questionable what role overlap has to play in their proposal".

The resistance to give up this metaphysics only serves to limit progress elsewhere. If these metaphysical questions are too deep, Saunders and Wallace should resist any explicit endorsement of a preferred metaphysical framework—particularly one that leads to problems

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[20] This is another place where one may wish to introduce discussion of theories of persistence, most notably Lewisian worm theory or Siderian stage theory but this is largely tangential to the point being made: Tappenden's initial confusion is largely due to Saunders and Wallaces's talk of overlap in their discussion of the Parfittian fission analogy. More recently, Tappenden (2010 p.4) suggests that if vocal events are not common to Everett worlds as Saunders and Wallace advocate, then their original discussion of overlapping persons (contextualised by the Parfittian fission analogy) is, in Tappenden's words, "irrelevant". As such, I suggest that the Parfittian fission analogy discussion in Saunders and Wallace's (2008) paper is an example in which the Parfittian fission analogy is distracting, particularly within an account that aspires to be metaphysically agnostic.

[21] This is in contrast to the metaphysical picture of divergence. On this picture there is much less motivation to consider the relations between agents and successors (in the way described) since agents are world-bound and therefore do not have multiple successors in this sense.

for their semantic theory. Proposing an account that resists endorsement of *any* metaphysical framework in answering these sorts of questions is an ambitious challenge, but one step forward would be to omit any explicit metaphysical models, exemplified in this instance by the Parfitian fission case.[22]

A more recent case in which a fission setup has constrained an author's reading of a work is Adrian Kent's (2015) critique of a proposal by Carroll and Sebens (2014)[23], who introduce self-locating ignorance in a slightly different way. Following Vaidman (1998, 2011, 2014a 2014b), Carroll and Sebens suggest that probability arises in EQM from the fact that observers evolve into states in which they do not know which branch they are located. The authors exploit the post-measurement, pre-observation period of a quantum measurement; in this interim stage, an observer is described by a unique state—but there are two copies, one in each branch. Since by construction the observer is yet to know the outcome of the measurement, she is in a state of self-location uncertainty.

Kent (2015 p.214) suggests that in order for such an account to be successful, it must firstly explain how observers are always "split into copies" prior to observing the measurement outcome; secondly, how during this period, each successor is located on a definite branch; and thirdly how each successor is uncertain about the branch she inhabits. This is, Kent argues, a tall order: how can one be certain that the post-measurement/pre-observation state does represent two successors? One could propose a situation in which a sole agent has not interacted with the measuring instrument (and thus not interacted with the particle-apparatus-environment state) and thus has no uncertainty about this state or the branch they inhabit.[24]

Sebens and Carroll are sympathetic to alternative metaphysical pictures of EQM (see footnotes 4 and 28 in Sebens and Carroll 2018) but they choose to present their account with an implicit fission setup (pictorially represented in their figure 1 diagram). In a similar manner to Tappenden's initial (mis)reading of Saunders and Wallace, the fission setup of Sebens and Carroll has at least some part to play in motivating Kent's criticism, which gains far more traction if one interprets Everett worlds with fission in mind. If we instead appeal to the metaphysical picture of diverging Everett worlds, as Sebens and Carroll are sympathetic to, Kent's analysis is far less persuasive. On this view, observers always inhabit a single Everett world prior to

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[22] Saunders (2010b) has more recently argued that diverging worlds are consistent with the Saunders and Wallace (2008) semantics.

[23] This work is a preliminary version of the more comprehensive Sebens and Carroll (2018).

[24] In a proposal that extends Kent's analysis, McQueen and Vaidman (2019 §5) categorise this state as *absent self-location uncertainty*.

observing the measurement outcome, each successor is located on a definite branch, and each successor is uncertain about the branch she inhabits. And even if one does propose a situation in which a sole agent has not interacted with the measuring instrument (and thus avoided interaction with the particle-apparatus-environment state) one still retains uncertainty about the branch they inhabit.

Perhaps this wouldn't satisfy Kent, but the criticism in its current form would certainly have been less potent if Sebens and Carroll had made the possibility of this alternative metaphysical picture more explicit from the outset. Kent's view is unduly limited by only targeting a metaphysical picture associated with Parfitian fission[25] (a single pre-measurement agent being physically and psychologically connected with and continuous to multiple post-measurement successors) thus bringing into to question whether states represent agents as being in either one or two worlds. On this view, his worries are well founded: we can't always be sure observers are "split into copies" prior to observation and whether each successor is on a definite branch and whether the successor is uncertain about her branch location. If, however we interpret EQM more broadly to include metaphysical pictures beyond those that describe worlds as overlapping, these concerns are significantly weakened. Thus if Sebens and Carroll's view is not presented within a fission framework, there is far more scope to anticipate and alleviate the sort of worry expressed by Kent. This is another example in which an author has been directed towards arguments that only apply to a particular metaphysical picture of EQM. And given this debate is much more recent, I suspect that many authors still understand and conceptualize EQM in this way. Whilst in the work of e.g., Wallace (2012), Saunders (2010), Wilson (2011; 2020), and Gomes (2018) there has been a broad progression away from thinking within a fission framework, there is reason to believe that this evolution has not populated the rest of the philosophy of physics community.[26]

This concludes §7.4. I have identified two debates in which the adoption of fission cases in search of solutions to the incoherence problem has actively misdirected discussion. In §7.5, I address the fission analogy in view of the quantitative problem.

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[25] It's not obvious whether Kent has a particular theory of persistence in mind but again this is independent of the argument here: if Sebens and Carroll's view had not been presented within a fission framework, Kent's assumptions about observers splitting gain far less traction. His response makes no allowance for a view such as divergence.

[26] It is perhaps of no coincidence that the possibility of diverging worlds failed to be recognized until the late 2000s largely via Saunders (2010b) and Wilson (2011) and is still largely missing from contemporary accounts of EQM (e.g., Maudlin 2019 §6). Whilst close to the diverging interpretation in certain respects, Deutsch's (1985) proposal differs in a number of significant ways from the decoherence-based version of EQM that I discuss in this paper (see Wilson 2020 §2.2 for details).

7.5 Quantitative Problem

Recall that the quantitative problem asks: even if it's coherent to assign probabilities to the outcomes of measurements, why should these probabilities be given by the Born rule? I'll first discuss Greaves' (2007) aforementioned *caring measure* and secondly a structurally comparable example by Maudlin (2014).

Greaves' proposal is formulated with the Parfittian fission case in the background. The fission analogy is established as the framework by which one can resolve the problem, one need only tweak the conceptual details: if an agent expects to see a particular outcome with a certain probability, one can replace the expectation to see a particular outcome with an equivalent distribution of concern for the successor associated with that outcome. My care for all successors can be partitioned according to branch weight; branches which have a high Born rule weight aren't more *probable* but they are more deserving of my concern. (For a dissenting view, see Albert 2010).

It's not clear, however, that the types of relations an agent has towards her successors in the fission case are anything like the relations an agent has towards her successors in EQM. The type of relations Greaves presumes for the Everettian are direct imports from the relations we suppose in discussions of personal identity, namely the *sole* pre-branching agent being physically and psychologically connected with and continuous to her successors. The type of relations in question are something like *causal* or *informational* relations and are at the root of discussions in fission cases; they constitute the central tenet about which personal identity claims are informed. But there is no reason why the correct metaphysical picture of Everettian branching should hinge on these concepts.

We can distinguish three types of distinctness common in discussions of cosmology that may help clarify ways in which causal or informational relations can fail to establish. The first is the inability to signal: the distance between two regions may be increasing at a rate in which any successfully transmitted signal between regions would have to be superluminal and is therefore ruled out. The two regions may inhabit a common spacetime but due to the expansion rate can never signal to one another.

The second type of distinctness is spatiotemporal isolation: two worlds are spatiotemporally isolated if the respective spacetimes of each world are distinct, perhaps varying in dimensionality and physical constants. Each world occupies a distinct spacetime and is therefore causally isolated from one another.

Effective causal isolation is the third type, which is most pertinent to Everett worlds.[27] Our branch has not causal interaction with other branches, but the existence of other branches does go some way to explain the existence of the branch we inhabit. Popular discussions of EQM, despite acknowledging the distinctness of post-measurement Everett worlds, often conflate these notions, proposing a causal interaction between worlds that causally contributes to events observed in each of those worlds. I don't think that this suggestion is quite right. Whilst the existence of other worlds may help to explain features of the world we inhabit, this does not entail that such worlds are causally interacting.[28]

It is also worth distinguishing between causal and spatiotemporal isolation simpliciter and causal and spatiotemporal isolation on the assumption that worlds overlap (worlds have a common causal and common spatiotemporal origin but are isolated post-branching). Different ontological pictures of EQM will have different things to say about the causal chains of events on this view[29], but for my purposes even if interpretative strategies differ in how to understand agents and successors in Everett worlds, any causation allowed under these strategies is not the type of causation that matters for our interests, namely as an analogue to the Parfittian fission model.

If there is any reason to think that the casual and informational relations identified in the fission case do not hold in EQM, one should be hesitant to endorse any measure over Everett worlds that depends on such links.[30] One way these links can be severed is by adopting the divergence view. If consistent histories are interpreted as diverging Everett worlds, it's much less persuasive to suggest that I should care more about my successors in branches with high weight. In fact, what could the locution, 'my successors' refer to on such a picture? If I inhabit a single Everett world both before and after a quantum measurement, there is only one 'successor'. And given I only have a single 'successor', the causal and informational relations I have to inhabitants of other worlds on the divergence picture certainly do not hold in a manner described by the fission case, or in the manner assumed by Greaves' caring measure.

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[27] Decoherence suppresses interference between macroscopic superpositions to a negligible level—enough to explain the fact that superpositions are unobserved—but does not suppress interference entirely.

[28] See Wilson (2020, §1.6).

[29] For example, the spacetime state realist (see Wallace and Timpson 2010) may suggest that spacetime and the quantum state are encoded in such a way that one is justified in attributing causal properties (of some description) between Everett worlds.

[30] One again might consider a stage-theoretic analysis here; whilst I concede that such links may hold on a stage-theoretic picture where aggregates of stages overlap, the key point is rather that such links are unavailable if Everett worlds diverge. And since divergence is a viable metaphysical option for the Everettian, one should maintain a degree of scepticism over any attempt to endorse a measure over Everett worlds that depends on those causal and informational relations.

Given the formalism makes no distinction between overlap and divergence, I think Greaves' argument requires a reason why the informational and causal relations she derives from the fission model are no different in the Everettian case. The viability of the divergence view is reason to doubt Greaves' use of the analogy. If the branching structure of EQM permits both an overlapping and diverging reading of Everett worlds, then this is good reason to reject a thesis that hinges not simply on causal relations between worlds, but on the assumption that these causal relations are robust enough to assign a measure of *care* between an agent in one world and her successor in another. Diverging worlds severely weaken these relations.

But suppose that the reader has doubts about divergence and wishes to retain an overlapping view of Everett worlds. Even if one assumes overlap, there is a further assumption that states the relations between an agent in one world and her successors in other worlds are structured in such a way that warrants a measure of care over them. It is one thing to propose that Everett worlds are in some sense causally interacting, but it is another to say that these causal interactions are of such a nature that one is justified to project in-world notions such as care on to them. And in light of the residual disanalogies, this is enough to cast considerable doubt on Greaves' fission-inherited relations between agents and their successors. [31]

Consider the disanalogy of spacetime connectedness and energy/mass (in §7.3). It is granted that on the overlapping view, worlds have initial segments in common, but the relevant post-branching segments of worlds are causally disconnected. A marginally more accurate Parfittian fission analogy may be to immediately send one of the post-fission successors in any direction away from Earth at the speed of light following the hemispherectomy. But even then, the successor doesn't take the whole universe with them and the reduced energy/mass of each post-fission brain hemisphere isn't analogous to the energy/mass in branching Everett worlds. The Parfittian fission intuitions in the EQM literature certainly weren't generated by considering the fission of entire universes. And so even if the analogy is nominally recovered in that scenario, it's not recovered as a philosophically interesting analogy anymore.

We therefore have a primary route and a secondary route available to place doubt upon the causal and informational relations that Greaves assumes. The primary route is the more direct path: the divergence view severs the links necessary for Greaves' caring measure to take hold. If one is willing to accept divergence, the viability of this metaphysical view is reason to

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[31] Greaves' proposal employs talk of *person-stages* but has little comment on Everett world ontology. As suggested in §7.3 however, even if worlds are identified with stages of their histories, there is little reason to think that theories of persistence undermine the proposal here. It's an open question whether the relations that Greaves adopts from the Parfittian fission framework can be unproblematically utilized in an Everettian setting.

problematize Greaves' use of the analogy. If on the other hand, one is hesitant to renounce commitment to the overlapping picture, there is an alternative route available: if one assumes overlap, there is a further assumption that the relations between an agent in one world and her successors in other worlds are structured in such a way that justifies a measure of care over them. And in light of the remaining disanalogies between EQM and fission cases, there is good reason to doubt that the relations between an Everettian agent and her successors are robust enough to attach such a measure of care to them.

If the fission framework had not been central to the setup of the problem Greaves aimed to solve, there would be little reason to insist on the causal relations she supposes between agents and successors. By analysing the methodological aspects of her argument, it becomes apparent that the fission context of being physically and psychologically connected with and continuous to one's successors has a significant role to play in driving her argument towards the idea of a branch-weight-relative distribution of care. If the problem is set up to assume such relations are explicit in the structural evolution of an Everettian agent, a system proposing a branch-weighted measure of care is a natural solution. The fission case encourages Greaves to project relations that hold between agents in our everyday experience on to agents and successors inhabiting distinct Everett worlds. The same assumption is prevalent in the Maudlin example case, which I turn to next.

Maudlin (2014, p.805) introduces us to an agent facing a choice concerning a malfunctioning nuclear power station. Option 1 in Maudlin's example states that "about half a dozen workers will be exposed to lethal doses of radiation" while "Option 2 gives a 99.99% chance (according to the standard quantum mechanical calculation) of shutting the reactor down and avoiding the radiation but a .01% chance of causing a chain reaction that will cause 1000 deaths." Option 2 would thus seem the more reasonable course of action since the expected value for mortalities is much lower. The chance of killing 1000 people is sufficiently low to warrant saving half a dozen lives.

If one endorses the Everett interpretation however, then according to Maudlin (2014 p.806), "…choosing Option 2 is, with certainty, condemning the 1000 people on the "low amplitude" branch, people just as concrete and real as anyone who ever existed." If one comes to believe EQM, it is therefore rational to reject Option 2 on Maudlin's view since "there is no "good outcome" from an objective perspective". Maudlin, like Greaves, takes familiar causal and informational explanations we attribute to physical systems in everyday experience to apply straightforwardly to relations between an agent inhabiting an Everett branch and agents inhabiting subsequent post-measurement branches.

Nothing in the formalism encourages Maudlin to presuppose the causal and informational relations which make it true that "choosing Option 2 is, with certainty, condemning the 1000 people on the "low amplitude" branch." Again, there are two routes available to cast doubt upon Maudlin's proposal. If one takes the more direct approach and accepts the diverging picture, then choosing Option 2, with certainty, does *not* condemn the 1000 people on the low amplitude branch. Divergence describes Everett worlds as non-overlapping, distinct entities; there is no obvious reason why one should trace the post-measurement collection of events in a plurality of Everett worlds to the pre-measurement actions of an agent inhabiting only one of those worlds.

If on the other hand one sets aside divergence, and advocates an overlapping picture, there is still a further assumption that states that an agent in one world (pre-measurement) and those in other worlds (post-measurement) are related in such a way that it is cogent to propose the agent in Maudlin's example is, with certainty, condemning "people just as concrete and real as anyone who ever existed". Maudlin makes an inference from ethical claims between in-world agents to ethical claims between Everettian agents. And again, a fission context of being physically and psychologically connected with and continuous to one's successors is at least one assumption that leverages an inference from ethical claims between in-world agents to ethical claims between Everettian agents. If we take the disanalogies of §7.3 seriously however, there is good reason to doubt this move.

I have suggested two examples in which authors have an insufficiently motivated bias towards a particular metaphysics when understanding implications of the quantitative problem in Everett's theory. Their conclusions are informed by conceptual machinery inherited from the assumptions of fission scenarios rather than assessing conceptual features of Everettian branching. The principal reason, I suspect, that Greaves and Maudlin raise no concern about the nature of causal relations they endorse is, at least in part, due to the fission case being so central to the conceptual framework prevalent in each authors' thinking. In the final section, I turn my attention to the epistemic problem.

7.6 Epistemic Problem

Much has been written about the epistemic problem (namely, how our empirical evidence is justified according to EQM), but I'm going to focus on one strand, namely quantum Russian roulette. The idea is the following: engaging in activities in which there is a high risk of death, I will always have a successor who survives and therefore gains private evidence[32] that EQM is true. I propose that this idea has received widespread but unjustified attention. I begin with the setup and argument, then give reasons to doubt standard responses to the problem, and finally put forward my proposal.

Quantum Russian roulette is as follows: a gun is modified so that its trigger is connected to a device which performs a quantum measurement. The state of a particle is set up such that upon measurement of say, its *x*-spin, the outcome of the measurement is spin-up with some probability and spin-down with some probability. If the outcome is spin-up, the gun does not fire; if the outcome is spin-down, the gun fires. Thus, on the Everettian picture, after the trigger has been pulled, there is a branch in which the gun did not fire and a branch in which the gun did fire. And so, if a willing participant were to play quantum Russian roulette, that is, if a willing participant were to point the trigger at herself and fire, the trigger can be pulled safe in the knowledge that her successor on the spin-up branch will always survive. In other words, since (purportedly) there is always a successor that survives post-measurement, there's no danger of death involved in quantum Russian roulette—so why not play?[33]

Everett himself reportedly pondered its significance (Byrne 2010), but more formal arguments didn't arrive until decades later.[34] Price (1996) endorses the view as a way to illuminate problems of Everettian probability, and along with many others, questions the epistemic status of EQM. Price (1996) Tegmark (1998) and David Lewis (2004) all suggest that if EQM is true, and one repeatedly attempts quantum suicide, you will experimentally convince yourself of its truth, but you will struggle to convince anyone else. Given the lack of public testability, Peter Lewis (2000) claims that we can never *believe* the Everett interpretation. Like many others, he cites the fission analogy in the setup to the discussion of quantum Russian roulette.

The argument for quantum Russian roulette is as follows. Typically, one makes choices in proportion to the probability that those choices generate good or bad outcomes to the respective successors, but in the case of life-or-death situations, one should never expect the 'experience of being dead'. One should not weight branches in consideration of certain-death branches, rather branch weight should be renormalized once all certain-death branches have been discarded. In consideration of the setup above, once all certain-death branches are

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[32] The notion of private evidence is employed in e.g., Price (1996); Tegmark (1998); P. Lewis (2000); D. Lewis (2004).

[33] For ease of presentation, this formulation is in the overlap setting (consistent with the majority of extant discussion of the topic) to optimally setup my critique.

[34] Squires (1986) is one of the first.

discarded, that just leaves the successor on the spin-up branch and the probability of survival is therefore 100%.

Arguments against quantum Russian roulette have predominantly been occupied with the philosophy of death. For example, Papineau (2003 p.54) claims it is "cogent…to care…about my secret garden after I die, even if I know that no conscious being will ever enjoy it." Wallace (2012 p.370) suggests that the failure of continued consciousness, or the failed realization of our desires in *some branch* contributes to the "badness of death". And Carroll (2019) similarly argues that the prospect of being dead in the future affects us in the present, and one's yearning for a long and happy life for all future successors is equivalent to the hope of happiness and longevity on a single-world view. It's again clear that being physically and psychologically connected with and continuous to one's successors as per Parfittian fission is motivating at least some of these responses.

I suspect the role of the fission case within discussions of quantum Russian roulette has led authors to attach an unjustified level of plausibility to the idea. Firstly, for all who endorse diverging Everett worlds, quantum Russian roulette simply doesn't get off the ground. Upon pulling the trigger, there will be no continuation of consciousness in the manner supposed by the above authors. If the trigger is pulled and the device measures spin-down, the unfortunate participant will straightforwardly die, with no room for any psychological or physical continuation. Each quantum Russian roulette participant inhabits a single distinct world and will either die or survive in a manner analogous to classical Russian roulette. Authors have little motivation to deduce the purported conclusions from the quantum Russian roulette experiment on the diverging picture.[35]

As such, one can't refute the idea that quantum Russian roulette is correct over and above the distinction that being physically and psychologically connected with and continuous to one's successors is correct. Perhaps this metaphysical claim is perfectly obvious—so obvious it need not be mentioned within formal discussion—but I suspect that this omission goes some way to show how deeply rooted the fission case is to this debate. The relations between the pre-branching agent and her successors in discussions of quantum Russian roulette are inherited directly from the relations between the pre-fission agent and her successors. It therefore seems philosophically valuable (at the very least) for this presupposition to be made explicit prior to discussion. If EQM is true but Everettian branching is not analogous to the fission case, then

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[35] It's worth noting that given Saunders and Wallace's (2008) account is a metaphysically agnostic semantic proposal, I presume it leaves open whether the inevitable survival of quantum Russian roulette would be avoided.

pace Lewis et al, the theory that private evidence is gained after each quantum suicide simply does not fit with the theory.

Authors such as Wallace, Carroll and Papineau have turned to the philosophy of death in an attempt to attenuate the force of the argument, but I think this domain is insufficient to probe the true depth of the problem. The issue isn't whether we should consider the badness of death as the failure of continued consciousness somewhere in the multiverse, or the failure of our dreams being realized in only some branches, but it is rather the more fundamental, conceptual issue of the extent to which we can attribute to branching Everett worlds the type of conceptual features presented in the fission case. The answers to higher-level questions concerning the "badness of death" and its ethical significance in a multiverse are sensitive to changes in branching structure. The branching structure informs how much I should consider other branches in discussions of quantum Russian roulette. And given there is reason to doubt the structural features of branching which make quantum Russian roulette ostensibly cogent, authors should emphasise that the argument may be rejected from the outset by highlighting disanalogies with the fission case it presumes. This response gets to the core of the problem.

Quantum Russian roulette has thus received a disproportionate level of attention in the literature. It should be disconcerting to Everettians that the defence of EQM has thus far hinged upon an ethical and moral philosophy of death. Such higher-level concepts are not explanatorily sufficient to settle a dispute that resides at a more fundamental level; a true explanation must address the structural features of branching, upon which the higher-level concepts can only then be answered. Everettians should concede that quantum Russian roulette is indeed a possibility but given how much scope there is for an Everettian metaphysics, we ought to reserve a degree of scepticism about arguments which presuppose that Everettian branching and cases of fission are analogous. The formalism of EQM has no commitment to the metaphysics of the fission picture. Rather than focusing on the aforementioned suggestions concerning the philosophy of death, Everettians have deeper, more explanatory powerful, and more persuasive arguments available to blunt the sharpness of the quantum Russian roulette challenge.

Everettians have either explicitly or implicitly employed the Parfittian fission case analogy as a means to disentangle conceptual problems in EQM, but this project has assigned little significance to disanalogies between fission cases and Everettian branching. Here, I've argued that much of the discussion of the probability problem over the past 20 years has been predicated on a problematic analogy that is not clearly supported by the physics. The relinquishment of fission-style analogies motivates a more robust, more perspicuous debate that does not draw on details informed by conceptual machinery inherited from the assumptions of fission scenarios.

Conclusion

I have argued for *physical anti-absolutism*, a view that says there is no sense to the idea of an absolutely general physical domain. At the start of this thesis, our pre-theoretic expectations almost certainly didn't include the thought that the *universe as a whole* is not well-defined, but such expectations carry very little weight in something as fundamental as the physics and metaphysics of totality. The success of a physical theory can be affected by different ways of carving up the world—a theory can be explanatorily more or less successful depending on the chosen scheme for describing a realm of natural phenomena (chapter 1).

Understanding how to bridge the gap between the representational resources (e.g., mathematical concepts) of a physical theory and the domain it describes opens the doors to a metaphysical picture which rejects an ontology that is distinct from the methods used to represent the world. This more modest metaphysics relinquishes the assumption that there *is* a metaphysically significant way for the world to be and motivates a view in which one can always use a given domain of objects to expand one's original domain; a view which carries over to some of our best physical theories (chapters 2 and 3). If we take seriously the idea that there is a metaphysically significant demarcation of the world, and that quantum theory is equipped to represent it then it's not clear how or in what way the world can be represented as it is in itself (chapter 4).

Whilst it may be true that quantum theory has made significant progress by either modelling systems as either isolated or tracing out a system's environment, an alternative picture is one in which quantum systems are open systems. And given one can formally represent these systems under a view in which open systems are taken to be fundamental, there is little reason to insist that closed systems being fundamental is the preferred metaphysical description of reality. Even within the domain of Everettian quantum mechanics, known as *unitary* quantum mechanics, one can still give a coherent description of reality including its emergent worlds (chapter 5). Moreover, *physical anti-absolutism* challenges the notion of *nothingness* since one can never coherently speak of the domain they hope to empty of all objects (chapter 6).

And finally, I suggested that there is reason to reassess a metaphysical picture which is frequently associated with EQM. Understanding Everett's theory by analogy with Parfittian fission cases enforces a particular metaphysical approach to EQM that limits its relevance to the philosophical questions that I hope to have raised (chapter 7).

It's of course surprising, counterintuitive, perhaps perplexing or shocking that totality isn't afforded a well-defined physical description, but these aren't *themselves* arguments against the view. The most important considerations in favour of understanding the metaphysics of totality in the context of physics is that it engages with the physical theories that have—and continue to—successfully describe the world. As noted by Wallace (2012, p.424), analytic metaphysics has been woefully unwilling to engage with modern physics[1], instead favouring "the philosophy of A-level chemistry", as Ladyman and Ross (2007, p.24) caustically put it. By considering the details of our most celebrated theories of physics, such theories are (I have argued) far more hospitable to the results and ideas in the logic and metaphysics of totality than our intuitions have hitherto permitted. I hope therefore to have at best convinced the reader that indeed there is no sense to the notion of an absolutely general *physical* domain and at worst motivated future discussions of fundamental concepts such as totality to engage with our best physical theories of the world.

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[1] There are of course notable exceptions, e.g., Ismael 2016; Wilson 2020.

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