ABSTRACT

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This dissertation is an examination of the foundations of what I call a "fourth" tradition of analytical-scientific philosophy, the tradition of "structuralism". It is a disavowal of a metaphysics of substances and/or entities in the pursuit of scientific theory and truth. We look, in particular, at the current manifestation of this tradition, which advances the thesis of "structural realism"; we ask how tenable this thesis is, and whether we can weaken it. I argue that we should focus on methodology—a program for the formulation of scientific hypotheses about the sorts of things there are—rather than on metaphysics *per se*. We replace "substance" with "relation" as the basic ontic posit, and hold that substances or entities are metaphysically *derivative from* relational structure. Thus, the thesis is not that "there are no things" (or that "everything must go", as Ladyman *et al*. suppose); rather, the thesis is that the things (entities or substances) are relational structure, and there is no *complete* specification of an independent entity *that is not itself more relational structure* (so a metaphysics of substances is merely secondary to that of relational structure). I also suggest that

there is no complete, unitary or monistic theory of what 'structure' *itself* is. That is, I hold that there is no "total" structure of which everything that is relational structure is a "part", on the grounds that this would constitute an "illegitimate totality" in Russell's sense (the claim that "everything is structural" does not mean that there is a single structure which everything has—what a monistic theory of structure seems to demand). We then turn to the question of scientific explanation in light of structural realism: can there be explanation without a metaphysics of substances? I answer affirmatively. I then turn to two cases where, I argue, structuralism (and the specific thesis of structural realism) is in play regarding scientific explanation: quantum information theory, and the recent attempt to render quantum mechanics local by re-interpreting physical law *time symmetrically*. I conclude with a consideration of some objections to structuralism, and an articulation of the general view of metaphysics that structuralism seems to presuppose.

STRUCTURALISM AND NATURAL PHILOSOPHY. METHOD, METAPHYSICS AND EXPLANATION.

By

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Dedication

I would like to dedicate this dissertation to the memory of my grandfather Ernest Cardella, who first encouraged in me a philosophic spirit of perpetual questioning, and who gave me a true sense of wonder.

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I would like to thank my academic adviser and committee chairman, Prof. Jeffrey Bub, for his profound influence on my work here, and on my life as a thinker. Also, I would like to thank Michael Silberstein for our long-standing dialogue, both personal and philosophical, without which I would not have found my way into the discipline of philosophy.

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Chapter 1: On the "fourth" tradition of analytical-scientific philosophy: structuralism; and a proposal to modify its foundations.

1. Three Traditions. In the history of scientifically-oriented philosophical thought[1] since the mid to late nineteenth century, we can find at least three traditions. Each tradition associates itself differently to the scientific tradition and each takes there to be some important relationship between metaphysics and scientific/empirical inquiry (sometimes a negative one), though they will differ as to exactly how the two are to be related.

As a reaction to the excesses of post-Kantian (mainly continental European) philosophy, there arose a tradition of linguistic-analytic philosophy whose main purpose was the investigation of the structure of thought, in particular, a logical analysis of concepts. The rough motivating principle here is that only by clarifying our concepts (derived from experience) can we get a handle on what there is in the world to be investigated. With analytically-scrutinized concepts in hand, science and philosophy (and, in general, human intellectual inquiry) may proceed unencumbered by specious metaphysical propositions. The method of this tradition is to take "pre-reflective" or "pre-philosophical" notions, subject them to logical/conceptual analysis, and to discover the rationally-purified concept worthy of belief and intellectual use. Only such purified concepts can be used to construct (or reconstruct)

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[1] By this I mean those thinkers who were explicitly concerned with science or who were themselves scientists or mathematicians or logicians engaged in philosophical pursuits (people like Poincaré, Frege, Russell), or who, aided by the methods of formal logic, puzzled over philosophical problems as problems of the use of language (people in the tradition of "analysis"). For a historical-philosophical sketch, *see* Beaney (2009)). These thinkers are all "scientifically-oriented" in spirit if not by the character of their actual written work.

human knowledge by which we may then (as rational agents) engage the world in science, ethics, politics, and the other disciplines of human knowledge. In metaphysics, we are, then, guided rigorously by this analytic method, licensed, that is, in asking such questions as what is the "ontological status" of anything at all—numbers, fictional objects/characters/events, properties, time and space, 'abstracta', etc. We may ask whether there are any "concrete" objects and what their nature is: tables, trees, people. We are also invited to inquire into the 'nature' or 'status' of such notions as personal identity, freedom (of the will), ethical values, the mind, and other classic philosophical problems, guided by the tools of conceptual analysis. Some have pointed out that this analytical tradition of metaphysics is a form of neo-Kantianism, where the focus is on the structure of our concepts of the world, since it is *concept* that links (subjective) human knowledge and understanding to the (objective, mind-independent) world.

But some, like Dummett, Quine and Putnam (in different ways), have called into question the very idea of a "mind-independent reality", arguing that the notion of 'truth' that underlies such an idea is suspect or untenable (Loux 2002, xiii). As a reaction to this skepticism, some have called for, and engaged in, a return to "a traditional view about the relationship between thought/language and the world … which can be traced back to the origins of philosophy in the Greek period" (*ibid.*). This strand of analytical metaphysics is not so much concerned with the structure of thought per se but with, following Aristotle, "being *qua* being"—the (mind-independent) nature of the world, "correspondence to which makes our beliefs/statements true" (*ibid.*). Thus, we find a reintroduction to such (perennial) problems as realism/antirealism, universals/nominalism, concrete particulars/substrata/bundles/substances, and "the necessary and the possible" and "persistence through time" as putative philosophical questions in their own right, which can be investigated more or less independently of the details (or history of) science – i.e., *systematic empirical inquiry*. I shall dub this the "first tradition".

Roughly at the same time as we saw the rise of "analytic philosophy", we saw the emergence of what we can call "scientific philosophy"—philosophy concerned to purify metaphysics by not so much conceptual or logical analysis per se, but by the subjugation of metaphysics to scientific hypothesis, methodology and the rigors of mathematical/logical thinking. In its extreme form, this scientific philosophy became positivism—the infamous "Vienna Circle", for example—an extreme renunciation of metaphysics as a positive thesis about the nature of reality, from Plato and Aristotle, through Kant and those who reacted to him. Experience and observation is all we need, says this school of thought. Even if it makes sense to talk of a reality "behind" appearances, to which some of our concepts may refer, and correspondence to which they are made true, such notions are irrelevant to the discoveries and activities of science and hence may be ignored. Human knowledge is produced only by systematic empirical inquiry, and the 'nature' of knowledge is not truth *qua* metaphysical relation between concept and world, but truth as *empirical reliability* and *theoretical success/ predictive power* and *technological advancement*. Reflexive, second-order questions such as "what is the nature of X?" are fruitless, futile and meaningless and cannot be answered whenever detached from experience and systematic empirical inquiry. This school ranges from metaphysical agnosticism to complete rejection of metaphysics in favor of “experience” (“sense data”) and observation. Let us dub this the “second tradition”.

There is also a third tradition (perhaps more of a sub-tradition of the second), going back to at least Quine[2], which is a kind of middle-ground between the first and the second traditions—between the linguistic analyticity of the Anglo-American schools of the twentieth century and the trenchant metaphysical avoidance and extreme skepticism of the scientific philosophers of more or less the same time. These are, roughly, the philosophers of science who respect Quine’s dictum: to get your metaphysics (ontology), quantify over the theoretical entities referred to by your best science. Working from this rather minimalist metaphysical method, though, this tradition quickly fills with much more than simply a happy set of metaphysicians-cum-quantifiers: Quine’s dictum leaves much to be (metaphysically) desired. And here is where this tradition explodes with a variety of metaphysical/philosophical views: reductionists vs. emergentists; Humeans and anti-Humeans; ontological holists vs. reductionist atomists; and so on. In this tradition of serious engagement with science (i.e., bothering to learn the details of a science or sciences), we see a proliferation of metaphysical debates no less rich than in the first tradition, and certainly more metaphysically sophisticated than we saw in the second. This tradition is complicated by the fact that it employs some *a priori* tactics and metaphysics (from the first camp) for the needed task of *philosophically interpreting* scientific theories (the basic task of this camp is, to again refer to Quine, to work out exactly “what there is”). Out of this reciprocity between science and philosophy, these philosophers

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[2] *See* especially his “Two Dogmas of Empiricism” in Quine (1999) *From A Logical Point of View.*

provide a fairly sophisticated and subtle picture of the nature of the world, carefully guided by science (a source of fact about the world). Part of the potential virtue of this tradition is that it isn't committed to there being a radical separation between "speculative metaphysics" and natural science (recall that Quine's rejection of the analytic/synthetic distinction bought him, he thought, just such a blurred distinction[3]). Thus, for this tradition, part of the act of science itself—of what scientists themselves actually *do*—is to engage in speculative metaphysics[4].

But, the ontological minimalism of this tradition is both a blessing and a curse: we have gained a clear ontological program (quantify over theoretical entities referred to in mature science!), but broader metaphysical questions (like the metaphysics of properties, substances, etc.—the purview of "traditional" metaphysics) are left unchecked and unconstrained, it seems. For example, we are left with a metaphysical *carte blanche* when it comes to the following central, interpretive questions regarding scientific theories and science in general:

> What entities are there (possibly, apart from the propositions scientists utter, or the mathematical structures of a given theory), and what 'form' do they take?
>
> How do the entities of one science relate to the entities of another—are some more 'fundamental' than others, more 'real'—what? Is there an 'ontological hierarchy' as it were?
>
> *Must* we always accept the implicit assumption in Quine's dictum that we should quantify over the *entities*—indeed, *why must we accept that there are 'entities' at all*? Can't an ontology other than an entity-based

[3] He writes: "[o]ne effect of abandoning [the analytic/synthetic distinction] is … a blurring of the supposed boundary between speculative metaphysics and natural science" (1999, p. 20).
[4] And indeed, we find many of these philosophers publishing in *both* academic philosophical journals *and* (highly reputable) *scientific* ones. With respect to physical science, many of these philosophers participate in a community that concerns itself with the "foundations of physics". Frequently, these philosophers are also highly trained physicists, and often hold a graduate degree in some physical science. The sentiment of this community seems to be one of deep engagement with science, and even one of helping science develop.

> one be found or motivated by science? Indeed, *is ontology even possible without 'entities'?*

Is the *only* task of the philosopher-metaphysician to be a logician, carefully quantifying over the theoretical propositions of science (aside from the quandary as to whether such a logical interpretation of theories is ultimately tenable)? Are there no more metaphysical tasks than exercises in predicate calculus?

Indeed, we may be left with the suspicion that Quine's dictum is *too* minimalist, and that the fears of the old positivists might have been somewhat justified: what, we might ask, counts as idle metaphysics and what counts as helpful or 'good' metaphysics—cannot scientists, or theories, go awry? Surely we might be able to answer this question without being as naively minimalist as Quine, or as skeptical and empirically-obsessed as the scientific philosophers, or as *a priori* or obsessively linguistic as the analytic philosophers. Might there be yet another—perhaps deeper and more subtle—middle ground?

2. The Fourth Tradition. There is, finally, a fourth tradition, one that is the focus of this present study[5]. It is an altogether different tradition of philosophic and metaphysical thought associated with systematic empirical inquiry (the scientific tradition of the European Humanists, continuing to the present day). As with many of the traditions just discussed, we can find intimations of it throughout the history of philosophy, in the obsession with number and form in the Platonic and Pythagorean

[5] My focus is less on situating the fourth tradition historically so much as shoring up its basic philosophical framework and drawing out the implications it has on some current philosophical views. In so doing I will, naturally, be offering my own view of this tradition and as such this study cannot be considered a piece of historical scholarship.

schools, in the nominalist traditions of the Mediaeval scholastics, to the metaphysical agnosticism of Isaac Newton, who (infamously) refused to provide an ontological resolution of gravity into a substance or concrete mechanism (a “reality”, as it were, “behind” his mathematical equations which accurately captured the “appearances”). This tradition, though, most clearly emerged in close association with scientific thought in the late nineteenth and early twentieth centuries, in the writings of such thinkers as Poincaré, Duhem, Eddington, Cassirer, Weyl and Wigner, and which has seen some development (and sometimes renovation) recently in the writings of Worrall, Zahar, French, Ladyman and Chatravartty, to name a few professional philosophers taking up this tradition. We shall dub this tradition “scientific-philosophical structuralism” or just “structuralism” for short[6]. This fourth tradition shares some tactics and concerns of the other three traditions, but is also very critical of them (either implicitly or explicitly).

One common characteristic of what we can call this tradition’s “early” phase—one whose spirit is still alive in structuralism today— is a distaste for talk, especially in science, of anything like Aristotelian “substances”. Such unchecked metaphysical liberty, they thought, threatened to introduce an unwarranted proliferation of substances into our scientific conception (or speculations) of the world, one for every theoretical term in each theoretical domain: heat, energy, electric

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[6] In the history of philosophical thought, the term ‘structuralism’ has been used may times and with many different senses. While I do believe, as a matter of the history of ideas, that you can trace similar kinds of ‘structuralism’ in different intellectual traditions (scientific, philosophical, theological and so on), throughout this dissertation I use the term to mean a certain metaphysical/ontological and epistemological disposition when it comes to thinking about science and scientific theories. Sometimes the structuralism takes the form of a specific, positive, metaphysical thesis (e.g., the thesis that “only structure is real”), and sometimes it is more of a retreat from metaphysics (e.g., the thesis that “we can only know structure”, and not the nature of that which the structure is structure *of*).

and magnetic phenomena all seemed to cry out for an underlying substance to which the mathematics and physics corresponded. Theories were offered that postulated such substances as "caloric", or "phlogiston" or "aether" to provide a putatively "physical" (or at any rate, metaphysical) ground for thermodynamics or electrodynamics. The nineteenth century, for this reason, has become the modern-day anti-realist's favorite proving ground: many theories were accepted to some measure, yet their theoretical entities (now) are hopelessly non-referring. The structuralists of the late nineteenth century retracted in horror at this proliferation of metaphysical-cum-scientific speculation; but they argued for an abandonment *not* of metaphysics per se, but of *metaphysics as the postulation of substances or entities to which theories are supposed to refer*. The structuralism of this period was characterized by a blend of what we would now call "instrumentalism" and anti-realism (but about *substances or entities*—what you can call "cautious realism" [7]), reinforced by an epistemological thesis about the nature of human knowledge—that all we know or can access is *structure* and so our theories only reflect the nature of human knowledge as such, and do not reveal the "things in themselves" or the "inner details of nature", as some liked to say. Thus, we have a Kantianism about knowledge, married to an anti-Aristotelianism about metaphysics: the early structuralists didn't want to provide a *positive* ontological thesis about the *nature* of the reality behind our (structural) knowledge of it—and so were agnostic about nature's details and substance—yet they were happy to embrace the instrumental/predictive value of theories and their mathematical content as providing *structural* knowledge of the

[7] *See* Frisch (2005) for a discussion of what he calls Lorentz's "cautious realism", which he argues is "remarkably similar to the motivational realism Arthur Fine attributes to Einstein, which Fine characterizes as "half skeptical, half humble" (p. 661).

world (a decidedly *epistemic* stance, to be sure). Up until the mid to late twentieth century, little in the way of *positive* (constructive) metaphysical theses were advanced by structuralists for fear (it seems) of running afoul of Kant's powerful critical and synthetic philosophy, which claims to reconcile the metaphysical excesses of the rationalists with the metaphysical skepticism, both explicit and implicit, in empiricism.

The Transcendental Idealism we are left with from Kant seems to prevent any positive metaphysical thesis from being advanced *in the domain of empirical inquiry*, for the principle seems to be that no thesis about the things in themselves—which is tantamount, in Kant's view, to "the way the world is", the mind-independent world supposedly speculated on by the rationalists and ancients of ages past—is justifiable purely *a priori* and so *cannot* be itself the object of science. There are some concepts that we (must) bring *to* science for science to be possible at all (concepts of space, time, causality, etc.); but science itself does not provide us with *metaphysics*—that is, we cannot take metaphysical notions *from* science (or, at any rate, we cannot justify such notions as being true knowledge of the mind-independent world of "things in themselves").

The early period of structuralism leaves us in the shadow of Kantian Idealism, and room enough for only an epistemic structuralism focused on knowledge of nature, rather than nature "itself", and in particular about knowledge derived from science: scientific theories reveal only knowledge of structure, not the things in themselves. In what amounts to an attempt to turn structuralism into a positive virtue in the philosophy of science, rather than merely a Kantian retreat from metaphysical ‘natures’, John Worrall advanced the thesis that what is preserved in theory change—what remains true—is structure, not the theoretical entities to which a given scientific theory is assumed to refer (Worrall 1989). And it is this *structure*, therefore, not theoretical entities, one ought to be a realist about, if a realist at all, argued Worrall. Making the case with examples from physics, Worrall tried to show that there is a chain of structural continuities amidst the change from one (mature) physical theory to the next. One example (not the primary one) was the switch from Newton’s to Einstein’s physics: the former’s theory still obtains as a limiting case of the latter; hence, is restrictedly ‘true’. There is structural continuity between the two in the sense that the structure of Newtonian mechanics is derivable from the structure of Einstein’s, given the appropriate restrictions on the latter (velocities much lower than light’s).

Having crept out from Kant’s shadow ever so slightly, the question for the structuralist now becomes, “what is structure such that one can defensibly be a ‘realist’ about it?” Was Worrall advancing a *positive* metaphysical claim, some *mind-independent* feature of the world about which we ought to be realists? What seems clear, in any case, is that the very *least* that Worrall was advocating was the thesis that there is some *mathematical* structural continuity between theories, and, should we take theories to be about such structures, then, supposing those structures are true (in some sense) *of the world*, our theories got something ‘right’ about the world—the structure. The questions that remained for Worrall, however, were: what is the relationship between mathematical structure and physical reality, and what are you metaphysically committed to when (as a scientific realist) you hold that theories refer to (true) mind-independent structure? Assuming that these questions could be satisfactorily addressed, the larger question that would be left unanswered, though, is *what about Kant?* Can the epistemic structuralism of the (neo)Kantian be reconciled with this new, metaphysically-leaning, form of structuralism? Or have we gone back (regressed?) to a kind of Platonism?

2. 1 Structural Realism: varieties and aims. There are two general aims that the structural realist has. This first aim is *epistemological*: science provides us with some knowledge of the world; but what is that knowledge *knowledge of,* given that theories are usually overturned in time but yet might be highly confirmed or make relatively successful predictions (predictions which, we might add, can maintain their validity over time, through theory change)? That is, the structural realist wants to simultaneously answer the "pessimistic-meta-induction" (PMI) *against* scientific realism, *and* satisfy the "no miracles argument" *for* scientific realism in terms of what genuine *knowledge* science provides of the world. PMI insists that most, if not all, present theories will likely be overturned in the future, and so it seems implausible to regard them as *now* literally 'true' of the world. Famously, Larry Laudan (1981) provided philosophers of science with a long litany of scientific theories that were overturned, along with the entities they postulated. Despite the criticism against Laudan's argument—that most of the 'theories' he offered as examples of failure were, in their day, only marginally successful, if at all—there is something to Laudan's central worry. Science *does* change over time, and drastically (Aristotelian science vs. modern relativistic mechanics, e.g.). Yet, there is *something* right about *some* theories even though they may be overturned: Ptolemy's model of planetary motion, despite its Aristotelian trappings, does manage to capture the movements of (the visible) planets *relatively well* (though not precisely—but no theory is exact), and can still be used to predict their positions. To the extent to which older, now overturned, theories still have such usefulness, we may call them "relatively successful theories" and hence, in their day, mature. Only *mature* theories of this sort should be part of the PMI, not immature or unsuccessful theories (that is, those that didn't make many interesting or lasting predictions in their own day). But if only mature theories in this sense are part of PMI, then the suspicion is—at least according to the structural realist—that we don't have reason to be so pessimistic after all! It is precisely this suspicion that, in turn, dovetails with the "no miracles argument" (NMA), to which we briefly turn. Both PMI and NMA form an interlocking pair for the structural realist, in a kind of turning-of-the-tables on both the realist *and* anti-realist.

NMA says that the successes of some theories (especially those at present, like quantum mechanics and relativity) implies that they get *something* right about the world, even though they will most likely turn out to be false, or be otherwise overturned in the future. It would be a miracle, says the NMA adherent, if a theory were as successful as, for example, quantum mechanics (so very highly confirmed) and yet it turns out that the theory was entirely, or literally, false. It surely gets *something* right about the world; indeed, every successor theory must account for the relevant data at least as well as its highly successful (and hence mature) predecessor. But just what *is* right about a mature and highly well-confirmed theory?

Structural realism is an attempt to answer just this question. If successful, the structural realist would have satisfied *both* an argument against scientific realism and one *for* it. In other words, the structural realist would have gotten, as John Worrall sub-headed his now-famous 1989 paper, "the best of both worlds"[8]. Let's linger a bit longer on this first aim of the structural realist. It helps us to better understand the *epistemological* dimension of structural realism, as opposed to the *ontological* dimension (which is the one we'll ultimately focus on in the dissertation as a whole)[9].

2. 2 Epistemic Structural Realism. In the context of the PMI argument against scientific realism, the structural realist points out that there *is* some continuity between overturned but relatively successful theories like Fresnel's theory of optics and the theory that replaces it (in this case, Maxell's theory of electrodynamics)[10]. The structuralist says that the right *structure* of nature was discovered, and this true

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[8] This suggests to me, although I won't try to defend this thesis at length, that there might be something very dubious about the distinction between realism and anti-realism. Indeed, given that Ladyman *et al.* in their defense of "Ontic Structural Realism" (OSR hereafter) propose that (their version, at least, of) OSR implies a kind of "naturalized" Platonism, where there is no fundamental metaphysical distinction between mathematical and physical structure, which, assuming also the viability of the overall structuralist reconceptualization of entities, individuals and so on, implies that there's little to dispute over between the realist and anti-realist. E.g.: no more "physical entities" as opposed to "abstracta", "numbers" etc. Perhaps the only lingering worry would be the old philosophical boogeyman of idealism/mind-dependence (though, as for this latter duality—that between mind-independence vs. mind-dependence—given that 'substances' have no fundamental metaphysical status, *even this* distinction is dubious from the structuralist point of view: 'minds' are just as much features of the modal/causal structure of the world as anything else, including the act of theorizing).

[9] Briefly, in the epistemological dimension of structural realism we try to explain just what sort of *knowledge*—relatively secure and lasting knowledge—we get from mature, successful scientific theories: and that is *knowledge of structure*, rather than "natures" or "essences" or "entities" per se. In the ontological dimension, we then attempt defend either of two theses, both of which are taken to be logically independent from the epistemological thesis that what we get from science is knowledge of structure: (i) what there is in the world is structure, *as opposed to* entities or essences or natures, and science is about that; or (ii) structure is *ontologically prior to* entity, nature, or essence (i.e., the mechanisms and things proposed as *underlying explanations* for phenomena), and so everything may be understood in terms of structure (note that this thesis is orthogonal from the first because the first tries to distinguish structure from 'natures', etc., whereas the second thesis does not). More on this below.

[10] *See* Worrall (1989), p. 155-160.

(or at any rate, phenomenologically accurate) structure gets preserved under a superseding theory. So, from the perspective of Maxwell's superseding theory, Fresnel's got the *details all wrong*, but the structural relationships captured by the mathematical equations of Fresnel's theory are structurally accurate, and consistent with the superseding theory (Maxwell's electromagnetic theory. Notice, that the structuralist (more specifically, *structural realist*) has an advantage here when it comes to theory change, the temporal dimension in this debate: science (or more specifically: scientific *knowledge*) is *accumulative* insofar as true, stable and invariant structures of nature are gradually discovered; and it is *revisionary* insofar as mechanisms, entities and "inner details" are gradually discarded in favor of richer, more successful theories. As for the NMA *for* scientific realism: there surely is no miracle that (mature) theories are successful, or that science can produce successful theories, on account of the fact that they get the *structure* of nature right—and, as the Fresnel case demonstrates, this structural success can be had *irrespective* of whether or not the true "inner details" of nature have been found. Let us call this aim—to find a tenable form of realism that avoids the primary arguments against it—a "second-order" aim. These second-order aims, so far, are consistent with "epistemic" structural realism, which is the (positive) epistemological thesis that all we (can) know is structure—that, as with Kant, all we have access to, given the creatures that we are, is structure and not "reality as it is" ("things in themselves") apart from our conceptual relationship with it. But this thesis treats scientific practice and theory as *merely an epistemic lens* out of which comes only knowledge, knowledge which is necessarily and always *mediated knowledge*—implying that one cannot "know" what is unmediated.

2.3. "Ontic" Structural Realism. The structural philosophy of science of Steven French and James Ladyman draws on some of the work of earlier structuralists like Cassirer and Weyl, and embraces an altogether radical form of structural realism Ladyman has called "ontic structural realism" (OSR). It claims to be more than a mere "epistemic" structural realism, and to offer us a *positive* metaphysical thesis: (relational) structure is all there is; individuals/entities are *metaphysically derivative* from (relational) structure. And it is this relational structure that is captured by our (mature) scientific theories. However radical this thesis is, these philosophers claim to be motivated not by some a priori philosophical commitments; rather, they argue, their metaphysics of structure is *motivated by fundamental physics itself* (adopting the maxim that one's deep metaphysics—ontology proper—ought to come from fundamental physics, a maxim it shares with the third tradition).

3. Proposal: altering the foundations of structuralism. Implicit in this fourth tradition is, it seems, a strong criticism of what I have dubbed the third tradition, the tradition to which, for example, Tim Maudlin subscribes. In his recent book *The Metaphysics Within Physics*, Maudlin put his finger (albeit unwittingly) on the central bone of contention (as I see it) between the third and fourth traditions (which is, at the same time, exactly what separates it from all the other traditions), and it has to do with the old question "what is Metaphysics?". Maudlin succinctly articulates the third tradition's answer to this when he writes quite plainly that "metaphysics is ontology"—with the (Quinean) proviso that ontology is provided by science (the doctrine seems to be that *fundamental physics gives us fundamental ontology*). And with this the structuralist tradition takes issue: the claim that "metaphysics is ontology" requires a reconsideration as to what counts as "ontology".

For the structuralists, ontology isn't a discovery, via science, of "what there is" in the *entity* sense of that term[11]. The general thought of the fourth (structuralist) tradition is something like the following. Science proceeds by postulating an entity or entities (or, more generally, a mechanism) by which its investigation into nature for a time proceeds but, says the structuralist, what we discover, finally, is not what the world is made of, or composed of, or what its "furniture" is. Rather, says the structuralist, science reveals a gradually widening breadth of structures, letting go of specifically postulated 'entities' *in favor of the invariant structural details of nature which those entities revealed (whenever they were successful)*. The physical or 'inner' details of nature are merely scaffolding by which we find nature's general structure[12]. The specific entities and mechanisms advanced by prior sciences are, on this way of construing structuralism, a *merely temporary* means of grasping the structure of nature, and as such, this project is inherently open and changeable in its details (mathematical and conceptual). Thus, metaphysics is not, as Quine would have it, a

[11] This renders Occam's Razor useless in one important sense: there are *no* "entia" to be multiplied, let alone *shaved*.

[12] And thus "reality" *versus* "appearance"—a classical distinction of philosophy that seems to have crept into natural philosophy (physics) itself—is changed by the structuralist from "natures" or "essences" underneath of "phenomena" to structure manifested by the physical processes and events observed in nature. How things appear *is part of the structure and order of nature too*, so that there is no fundamental distinction between "appearance" and "reality"—just different levels of structural analysis.

discovery of ‘what there is’ but what *form* or structure there is to what there is, come what may regarding the entities science does (or has or will) postulate—that is, what empirical relations there are, given a postulated theoretical framework. As the early structuralists (19th century) would have agreed, mechanisms, substances or entities are always put forward as hypothetical explanations for natural phenomena, and are therefore merely the entry-way into nature’s workings, not the complete or final story, nor one that reflects the “way the world truly is, in itself” (the emphasis here is on truth as complete and final, and as theories as mirroring or corresponding to this ontological truth). Structure is *left behind* in any mature scientific theory (and this, finally, seems to be the simple thesis Worall attempted to defend in his now-famous 1989 paper). The entities are the scaffolding which allow us to discern the invariant structure of nature; they are conceptual instruments that, like our material instruments of technological experimentation, allow us to glimpse a reality not graspable by ordinary means (by means of pure unaided observation or unsystematic, common sense notions).

I would like to propose that if we invoke a fundamental distinction[13]—that between questions of an “ontological”, as opposed to what I am going to call merely an “ontic” sort—and if we drop the (metaphysical) realism from structuralism (and hence from the debate altogether), we end up with a more defensible attitude towards science (and physics in particular).

[13] This distinction will be clarified in the next section. The distinction was learned from Heidegger’s well-known and influential study of metaphysics *Being and Time*, specifically deployed in the Introduction in order to clarify the “question concerning Being”. However, the distinction actually goes back to Aristotle (cf. Book IV, Gamma of *Metaphysics*, for Aristotle’s classic treatment). I use the distinction, though, to slightly different ends, and obviously in a new context.

According to the resulting view, it is better to understand the position of researchers like Steven French, James Ladyman and Don Ross (called “Ontic Structural Realism”) as offering a general methodological program for science (and physics in particular) that advocates the replacement of a naïve materialist causal-mechanical philosophy, which thinks that the only valid form of explanation and scientific understanding must ultimately be given in terms of an ontology of fundamental things or stuff/substances (Lewisian-Humeanism), with a more general and sophisticated construal of physical reality in which ‘relation’, rather than ‘thing’ or ‘independently existing substance’, is the more basic ontic-explanatory category (and from which one may *recover*, as less fundamental, but nonetheless physically usefully, concepts like ‘object’ or ‘individual thing’ or ‘independently existing substance’, etc. as special cases). Accordingly, the materialist causal-mechanical philosophy is taken to be merely a narrow form of the more general structuralist methodology, in which we presuppose some notion of object (the specific content of which is provided by some physical theory), and try to construct some (relatively limited) interpretation of the world using a single fundamental relation (that of composition, involving “mereological relations”) from that point of view.[14]

Two notable features of this project emerge.

First, all of the specific ontic details (substances, relations, etc.) are left open and a matter of whether or not one paradigm of thinking can or will be successful over others (or that possibly there will be a combination of them). Thus, from a

[14] One example might be the so-called theory of “Bohmian Mechanics”; another would be the sort of picture of the world that Lewis himself seems to derive (shared by some of his readers and critics) from Newtonian physics—what in contrast to a more avowedly quantum point of view we would call “classical”.

purely descriptive point of view, there are several proposals on what the fundamental nature of physical reality will require of our fundamental theories—some propose new entities (strings, loops), some propose that fundamental theory is going to be about 'information', and some, more abstractly, propose a more 'relational' view which replaces the view in which there are entities moving or changing in largely independently given spacetime[15]. *None* of these proposals are excluded from the running on purely conceptual or analytic grounds (logical consistency/cogency of concepts), because the assumption is that there is no prior fact of the matter as to "what reality really is". All of these proposals are taken to be valid possibilities, any one of which, if successful, would still only be taken in a conjectural sense.

Second, following on from the above remarks, the question as to the "truth" of some structuralist hypothesis (like "ontic structural realism") merely becomes the question as to whether or not the facts of our world tend to support the notion, and, in turn, whether or not such a hypothesis may be a viable empirical postulate. As for the

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[15] I will have more to say about this point of view, which is the view that, among others, Lee Smolin is pursuing (I have also published on the idea, though in a more philosophical vein; *see* Silberstein, Cifone and Stuckey (2008b), which has been appended to this thesis). I will be describing it in contrast to the view that entities are the fundamental ontic units of a theory (the basis upon which the world is divided, in terms of which fundamental explanations are advanced). For "relational" theories, the very means by which changing/moving entities are individuated (this has been space and time, or, since Einstein, "spacetime") is itself a dynamically evolving structure. This is the basic significance of general relativity, and it constitutes a rather radical departure from Newtonian physics (even more so than does special relativity, which really showed that space alone and time alone cannot really be considered as separate—general relativity added matter to this interdependency). Thus, matter and spacetime may be said, according to general relativity, to "co-evolve". Some theoretical physicists, like Lee Smolin (*see* his 2007) take this to imply a general principle (a meta-principle governing the form of fundamental theories), which is that no fundamental theories should be background independent (that the spacetime structure, which is fundamental to all physical constants and basic to our measurement of all matter, and the structure of matter, are coupled). Thus, part of Smolin's task is to find a consistent quantum theory of some kind that satisfies this principle. This is one way of specifying what "relational" really amounts to in physical theories, and I take it to imply that 'entity changing' and that which provides the arena of change are coupled in a way in which they were not for Newtonian physics (thus making a kind of atomism or mechanical philosophy more plausible). We'll return to this later.

question of support, the proper relation between science and hypothesis is, as Einstein held, one of "epistemological correlation": we drop the idea that science provides truth in the sense of correspondence to some ontological truth, since the supposition of such a truth is a trivial assumption of doing science, rather than that thing which science is aimed at "discovering". In other words, science does not aim at "Truth"—ontological sense—but "truths" in a limited and local sense[16], *the totality of which does not constitute Truth*. Let me explain what I mean here.

3.1 A fundamental distinction. In my view, 'metaphysics' is a study of, as Aristotle famously said, "being as such". We might say: a study of the "Being of beings". And so metaphysics is ontology, but ontology in this (older sense) *is not properly a result of science*—it is prior to science and, as it were, *beyond it*. The mistake has been to regard this "Being of beings" as *yet another something among things,* of perhaps a different ontological sort (of a "higher-order" level of reality), that can be studied in its own right and for which we may supply specific conceptions in order to make its nature explicit, and in order that we may have a "true view" of it (like we are taking a picture of a scene that stands already there before us).

Although I regard this as a flawed view and pursuit of ontology proper, I cannot defend that claim here. What is important is to distinguish the question of the Being of beings—ontology proper—from a more properly scientific or empirical question, which I shall call "ontic". Questions of this sort—what is the structure and nature of this specific being or domain of beings?—require the use of conjectures

[16] That is, the sense in which science must demarcate a limited domain of investigation, and on the basis of this limited scope, advance hypotheses, which in turn may, or may not, correlate with the facts, both established and potentially newly discovered.

(hypotheses), the aim of which is either to correlate them with the facts or, in the case when a conjecture is put forward as a postulate of a theory, to allow us to advance a general theory (which Einstein called a "theory of principle") which proposes to coordinate a certain classes of facts together into a theoretical whole (I am thinking of Einstein's remarks about classical thermodynamics here[17]).

In particular, when I speak about "ontic structuralism", I am speaking about the sort of metaphysical point of view that holds to the idea that entities are derivative from structure—structure being the primitive metaphysical category. This is "ontic" and not "ontological" in the sense that ontological claims stand *before* the empirical investigation and serve as a final and closed statement about the nature or essence of the beings science investigates (i.e., the provide us a *theory of* 'objects' or a *theory of* 'properties', etc.), whereas ontic claims *follow* empirical investigation and stay close to the empirical relationships that warrant the particular conceptions of 'objects' that are put forward hypothetically—without thereby implicating a "theory" of objects, properties, etc. For example, the concept 'electron' is controlled by our use of that term in the context of experimentation and in theorizing about the subatomic world; the ontic structuralist says that the concept 'electron' may be an 'object', but the object in question is inherently relational in character—no entity "stands outside" the structure of physical relationships that warrant the concept 'electron'. It is *from* those

[17] The advancing of a hypothesis, that is, may take one of two general forms:

(1) that of a specific mechanism (advanced on the basis of some preexisting or implied—possibly untested—theory). One famous example due to Einstein is the kinetic theory of gases, which presupposed classical Newtonian mechanics in order to write down the specific details of the interactions between gas molecules—the ontic units that formed the physical basis of the proposed theory.
(2) that of general postulates (like those of the Special and General Theories of Relativity), which actually regulate or constrain the *form of the laws that govern any specific mechanism that may be proposed within the domain of those postulates*.

physical relationships that we derive the concept ‘electron’. Indeed, an ‘electron’ *qua object* is, according to the ontic structuralist, what we can manipulate and control in the context of high-energy experiments, electrical-magnetic experiments, etc. We say that this ‘object’ is present under the right conditions and given the right energy indicators, fields, etc[18].

Science does study things—“what there is”—but it is not in the business of revealing the *complete* and *self-standing* ‘nature’ of reality, of giving us the ‘nature’ of any particular being upon which it sets its study, nor is it in the business of giving us the (metaphysical) ‘truth’ of nature. Indeed, nature is not the ‘thing’ we are inquiring into when we do science (nature may be a collection of things to which a

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[18] In other words, I am objecting to the *formulation and search for a completely ‘monistic’ theory* of objects to which *all* instances from *any* special or general discipline are conceptually bound (it seems to me that any monistic, *a priori* theory in analytical philosophy will have this character—i.e., constitute a regulative/prescriptive criterion as well as a theory to which all conceptions of ‘object’, ‘individual’ will be held accountable). In other words, I presuppose a *pluralism* of the ‘nature’ of objects, individuals, etc.—that is to say, the ‘nature’ of an object will be a function of the details particular to a domain of empirical inquiry, and the description of this will not necessarily constitute, nor need presuppose, a *general, monistic* theory of ‘object’. I submit that such a theory be *unnecessary*, and at any rate, insofar as the details of it must be measured against our best scientific theories, in the face of theory change, such “theories” will be as changeable and mutable as any scientific ones—thus we must be open to the odd fact that our notion of object if open, unstable and hypothetical. Such a demand (for a general, monistic theory of objects, individuals, etc.) seems to be too high: for we are always probing new areas of nature, and must therefore leave the nature of the individuals and objects *open*. It may be useful to construct a view of objects/individuals *on the basis of scientific theory, experiment and experience* (and I do this on the basis of a collection of “modal structures” encountered in the act of theorizing and experimenting with nature—the “happenings” and “doings” and, generally, counterfactual truths that are revealed as we manipulate and intervene in nature—objects just plainly *are* that abstraction we advance on the basis of this modal structure, whether or not the object has a kind of endurance or persistence across the variety of modal structures where we use the appropriate term, such as when we invoke the concept of ‘electron’). But usefulness—even if it clarifies ‘what we mean’ by an object in some domain or collection of domains, does not constitute nor depend upon a general, monistic theory in the analytic philosopher’s sense. If anything, which is required is a phenomenological/biological and psychological account of the acquisition of the concepts ‘object’ and ‘individual’ (something, e.g., Ladyman *et al.* (2007) allude to many times)—not an analysis of the concept as such in terms of the analytic conception of philosophical theory (often called ‘metaphysical accounts”). Any such analysis will serve to obfuscate rather than illuminate the actual basis for the concepts in question, and so fail to comprehend what we actually (rather than theoretically) refer to by concepts like ‘individual electron’ etc. See Ladyman *et al*. (2007), and references therein, for a more thorough articulation of this worry, as it is not the purport of this dissertation to take up this rather extensive and interesting problem. We must leave it to the side here.

science devotes its attention, but this collection *is not itself another thing* about which science may theorize, to borrow from Russell and Whitehead's theory of logical types). This sort of enquiry—into 'nature' as such—would be to slide back into a properly ontological enquiry, and thus to give up on science per se. Science proceeds in part by dividing off beings from one another (species, for example), or certain domains or collections of phenomena (celestial and terrestrial motions, for example), and postulates a theoretical framework for thinking systematically about those individuated beings or collections of phenomena. That is, we get a *methodology*, within which specific conjectures or hypotheses are put forth so as to allow the methodology to move forward in the sense of allowing for specific models to be constructed and later tested by means of laboratory experimentation (or by means of a systematic comparison of the regularities *already present* in nature without the intervention or mediation of technological devices *per se*—the "devices" in this case are the (conceptual) hypotheses put forward, in conjunction with a statistical coordination of observable facts, so as to produce a relevant and illuminating comparative study, from which further inference may be drawn).

In this act of giving definition and division to the things it studies, science *moves away from ontology* (the study of Being as such). From the point of view of the details of the beings that it sets out to study, it would be an error for science to turn back and reflect on what the nature of reality *as a whole* is, for 'reality as a whole' is what Russell once called an "illegitimate totality", and so not a proper object of study (we might call it a pathology of thinking). Nonetheless, we make speak about such things in their proper domain of enquiry (and this I take to be philosophy proper—or I should say, metaphysics); but we may do this only when we ask, anew, what is Being?, and only when we let go of the pull towards engaging this enquiry by advancing hypotheses in the manner of science (what was once called "natural philosophy")[19].

It is the nature of these postulations that they are temporary and tentative, not eternal and final. Science—and especially physics—changes as it pushes its postulates into wider and more remote domains of inquiry[20]. Thus, insofar as a definite 'nature' or 'substance' in the older metaphysical sense is understood to be something ultimate, or at any rate final and complete in itself, science does not purport to provide such a thing. Science does not take a "picture" of "ultimate reality". In other words, the very worry that Kant was addressing—that the "things in themselves" are beyond science, and that, therefore, we should understand empirical inquiry as providing an understanding of "things as they (merely) appear to us", rests on a series of *false premises*, the collection of which implies what Russell would have called an "illegitimate totality"—defined by the ideas of 'natures' or 'substances' which in turn 'compose' or in some sense 'constitute' an 'ultimate' reality, one that is supposed to be 'independent' of 'mind'. In other words, my argument is that the sum-total of the old metaphysics of substances, natures, etc., constitutes a conception of "ultimate reality"—the totality of what there is—which is entirely illegitimate. Hence,

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[19] It is not the purpose of this thesis to dwell on this particular issue, so these remarks will have to be put to the side so that our present study may proceed more or less unencumbered by such general issues.

[20] That is to say: those domains which are phenomenologically and instrumentally distant from the postulates and assumptions the science began with, as when we conjecture that ordinary classical thermodynamic considerations apply to blackbody radiation, which was famously discovered not to obtain. So science involves the gradual widening, elaboration and potential complete renovation of certain notions that it brings to bear theoretically.

we reject this metaphysics. Kant seems to think that this means we are bound to mere appearances, therefore. I say that insofar as the very idea of "appearance" itself depends upon the prior assumption of an ultimate reality in the sense I just mentioned, and insofar as that ultimate reality constitutes an illegitimate totality, *mutatis mutandis* for the "appearances" too. It follows that *neither* substances, natures, etc. ("ultimate reality") *nor* the appearances which "cover" this ultimate reality (which, again, are the "things-in-themselves", defined by their natures, substances, etc.) is the proper object of science. This is not Kantianism, and it is not neo-Kantianism. This is a new philosophical space which I believe ontic structuralists like Ladyman *et al.* are attempting to adopt, but which they have not fully articulated.

This new philosophical space—one which the modern day structuralists are struggling to define—lacks a reconsideration, and an up-turning into the light of critical reason, of the very foundations upon which the whole Kantian, and neo-Kantian, dialectic is founded. Kant, in essence, was responding to a philosophical problematic that arose out of Descartes' methodology and metaphysic, which itself encapsulates much prior medieval thinking about substance, essence and so on—all of which is itself a reconfiguration of Aristotle along Christian and neo-Platonist lines[21]. It is the Cartesian notion of substance, and what constitutes the 'nature' of things ('things' being instances of some underlying substance, of which, according to Descartes, there are two)—it is *this* particular construal of metaphysics (*one of substances* in the Cartesian-medieval sense) that, Kant argues, cannot be the (proper)

[21] My characterization of this vast historical period is rough, needless to say. For a beginning into this territory, I refer the reader to Josef Pieper's many lucid essays on the topic (*see esp.* his *Scholasticism*[1960]), and to Paul Tillich's *History of Christian Thought* (1967). For Descartes' metaphysical views, *see* Burtt's synthesis of original source materials in his *Metaphysical Foundations of Modern Science* (1932).

object of science *per se*, or even of *human understanding* more generally. Rather, such notions are the conceptual—and merely conceptual—foundations of our mode of knowing the world. The "things in themselves", which these notions are supposed to be capturing, always remain outside of, and are the so-called *transcendental ground* of, our inquiry into reality (or, a bit more specifically, into *nature*). The best we can do is to articulate the fundamental categories by which all knowledge of reality is made possible, and which all empirical inquiries must presuppose. So Kant does not so much as overturn the Cartesian metaphysic, as correct his methodology and the proper *aim* of that methodology: we can only know the appearances of nature, and can only supply the necessary presuppositions of that knowledge; everything else—the metaphysics of substances, ideas of causality, space and time, etc.—are the epistemic background, or rather, the conceptual ground we stand on when we gaze, philosophically, at nature.

But there is a prior question to Kant's, which is: upon what ground—prior to the realization that certain categories are perhaps necessary for there to be any knowledge whatever—does the notion of 'substance' rest? Kant says that that very question is unanswerable, since it asks something about the *ultimate* nature of reality (i.e., something *outside* the question itself), of which only appearances and the transcendental ground are knowable by creatures such as ourselves, confined to the use of senses, in possession of a limited mind, etc. But I say that *this* argument is entirely independent of my question, which is a question about what grounds *in reality* the notions of 'substance' or 'essence'—to which an epistemological thesis or a transcendental one is inadequate, because it presupposes that all questions of reality are of an ultimate sort and hence outside the domain of human knowledge. Why assume that? It is not clear, for example, that Aristotle, whose scholastic successors Descartes specifically has in mind—would have agreed with Kant that *all* talk about 'reality' presupposes an inquiry into 'things in themselves' as opposed to 'things as they (merely) appear to us'. Indeed, our own essence was certainly a fundamental mode of our experience, that is, *our very thinking itself is the essence to which we refer when we call man a 'thinking being'*.

Aristotle's notion of 'essence', arguably, is not 'metaphysical' in the same sense that both Descartes and Kant, roughly two millennia later, took it to be. Descartes took himself to be articulating that 'nature' of reality in the sense of providing the *mind-independent, unchanging verities which allow for certain knowledge of reality*. In other words, the dialectic surrounding the Cartesian and Kantian notions of essence, and substance, was fundamentally epistemological, whereas for the earlier Ancient Greek tradition, it was exactly reverse: the essence of anything was its 'inner principle', and insofar as we think, we 'know' (directly and immediately) our own essence, and from *that* certainty, we arrive at the inner principle of any other being distinct from our own[22,23]. At the top of this system was a Mind thinking Itself—Aristotle's "prime mover"—and so the very essence of reality was just a grander or more abstracted form of our own inner essence. That is, the

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[22] Aristotle was the first great methodologist, we may say: he proceeded by induction, and his thinking, importantly, begins with Ethics, not Metaphysics; that is, Ethics actually constitutes the basis of Aristotle's thinking. Recall that the "prime mover", as "thought thinking itself" is such as to think only the best, which is itself, so it must be "thought thinking itself". The notion of "best"—an ethical concept—is the heart of Aristotle's metaphysics (i.e., "Being *qua* being").

[23] Obviously, I do not have the time, nor is it the purpose, to defend this claim, which would take us far afield of this purport of this thesis; but nonetheless, we should at least note that the general point that I am making was defended by, for example, Schopenhauer (this in direct response to Kant's view).

basic structure of reality—its teleological structure—was of a piece with Mind. All things, by their inner principle, were "aimed" or "directed towards" the One Mind, which is like my own, but just more abstract (literally, self-absorbed in thought). No problem of certainty arose under this system, and there is no clear distinction between "mind-independent" and "mind-dependent", because even the "mind-independent" things—the beings distinct from my own mind—are comprehended under one Intelligence, and whose own inner principle (i.e., the inner principle of motion or movement of things) is inextricably bound up to the One Mind. Indeed, there is *nothing* "mind-independent"; the idea is incoherent for Aristotle. Only later, after the Scientific Revolution, when the Scholastic-Aristotelian system of predicaments (or "predicates") was effectively reduced to just a few (figure, shape, etc. or what later were called "primary qualities"), did the question of certainty arise—and this only after Descartes called into question all knowledge by way of his epistemic isolation of the knower to a metaphysically isolated domain mysteriously (by his lights) "interacting" with the outside (mind-independent) world of "extended bodies" ("*res extensa"*).

Descartes wanted to know what absolutely certain foundation there could be upon which knowledge might be erected anew, and proceeded from his own, individual existence outward, via the notion of a Deity (absolutely benevolent guarantor of the verity of clearly perceived ideas in the mind's theater), to what he took to be certain knowledge of "external world". This is a methodological requirement that in turn leads to a certain, definite epistemology and which, in its turn, leads to a certain ontology (in fact, we have a closed loop between metaphysics and epistemology). But in the end, Descartes could not call into question—by his own lights—a fundamental presupposition of *this* inquiry, which is, that “I am a thinking being”. He simply reasserts this as a necessarily true *foundation*. But where does this notion of individuality come from? Where is it that we arrive at the notion of an *independent* thinking thing, among a collection of other things *outside of the substance of the thinking thing,* for, by the lights of his methodology, every idea must itself have some certain foundation *outside itself*? In other words, part of the presupposition of Descartes’ starting point is already a distinction between internal reality vs. external reality. The former is the realm of the “mind-dependent” and the latter is the realm of the “mind-independent”. Science can know and study the latter exactly, for the nature of the external world is pure extension (i.e., geometry) itself; the former remains outside of its grasp (thinking substance is un-extended, and hence un-geometrical—therefore literally ungraspable). Kant corrects this by coming to terms with the Empiricism that comes roughly after Descartes: what we know is bounded by the limited nature of our senses, and so our rational deductions must be constrained accordingly; we don’t, properly speaking, ‘know’ that reality is composed of two independent substances (*res extensa* and *res cogitans* for Descartes), we must presuppose certain categories of thinking (substance, individuals, universals) by which we may acquire any knowledge at all, and those are merely the transcendentally necessary grounds for our thinking, not the ultimate nature of reality[24]. Keeping the distinction between “mind-independent” vs. “mind-dependent” intact, Kant simply fuses the two by way of his transcendental argument: certain ideas

[24] Or at any rate, insofar as this ground is itself part of the reality we grasp, it is the most we can know of the reality *itself*—as it ‘is in itself’, as the old phrase goes.

are necessary only insofar as knowledge is not possible without them; but as to whether or not those ideas reflect the mind-independent reality, we cannot, properly, have knowledge of that. These transcendentally necessary ideas (the categories) refract the things-in-themselves and return to us their mere appearances, colored by those necessary ideas. Kant, thus, manages a tenuous synthesis between Empiricism and Rationalism[25]. Kant does not go underneath the foundations of either; neither does Descartes.

We must face a question, though—one which has in it the heart of the question of "realism": what is science "about", if you have just parted with the tradition of thinking of nature in terms of ultimate reality (natures, substances, etc.) and appearances? The right reply is that we have dropped (indeed, we *must* drop) the "correspondence" notion of truth in regard to our scientific hypotheses (there is, in a sense, nothing of an ultimate, final sort that to which theories refer—the idea of "correspondence" presupposes an illegitimate totality), so the question of what science is "about" becomes instead: What does science *involve us into*? When the predictions and manipulations and interventions of a science are fairly reliable, then what may we say that we have understood, or grasped, by that science? Here is where, when the question as such is posed, we must take a stand[26]. This is where we

[25] Knowledge is a refraction of experience by way of necessary categories of thinking; so, rational deductions are, inasmuch as some of the elements/premises of that deductive activity are taken from this refracted conceptual-sensory knowledge, a function of our epistemic limitations and so are not necessary truths. Some rational deductions are, but those are of a purely conceptual nature and are devoid of any empirical content: they are, as all mathematical theorems are, "tautological" in the extreme, and can never tell us anything about the *nature of reality*, or anything else *outside* the realm of those conceptions.

[26] There is of course the retreat to yet another point of view, which says that there's no need to take a stand at all—I leave that issue, which is "instrumentalism" to the side. It will become clear that the position being defended here actually entails a kind of instrumentalism, but it does so not by construing instrumentalism as a retreat from realism since the question of 'realism' is simply

articulate our *attitude* towards science, where we take a critical and reflective pause to think about it as a whole, as a certain sort of human endeavor among others.

As we do science, we are involved into the world—into 'reality'—more and more deeply. Our notions of what reality 'is' must, therefore, *fluctuate* according to our deeper engagement with it, and according to our widening horizon of experiences (for example, our experiences with particle colliders, telescopes of various sorts, of the diversity of organic life, and so on). Thus, we arrive at notions of reality which are to some extent 'close' to our immediate, unsystematic and 'pre-theoretical' understanding of nature, and to some extent further from this. For example, my notion of what matter is—what even a table is—is to some extent a function of my immediate contact with it, and also to some extent may reflect what we know is true of all matter (that it is fundamentally quantum mechanical). This may seem a trivial observation, but it remains to be seen, for example, whether or not, and to what extent, *macroscopic objects of various sorts may manifest quantum mechanical features*. Supposing that this is a coherent possibility (and physicists like Anthony Leggett, for example, are exploring exactly this possibility), we must modify our notion of matter, and even tables (or whatever objects are subjected to quantum mechanical manipulations) accordingly. Thus, the notion that there is a radical break between what Sellars called the "scientific" (or we may say, "theoretical") vs. the "manifest" view, is misguided. We must face the eventuality that, as science teaches us something new about even our most basic categories of experience, we may indeed *need* to depend upon those theoretical determinations in even the understanding of

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considered inappropriate—it is an "ontological" question and does have its proper place, just not in science.

our own immediate experiences with reality. So, if anything, the distinction between the “scientific” and “manifest” views is fluid, and at any rate, indefinite. So too the notion of “theoretical” as opposed to “observable” entity.

So, the only problem with the notion of ‘substance’ or ‘essence’ is that it may just be too general and abstract, and perhaps not rich enough to account for specific experiences or experiments, not that it is overly metaphysical, or that it points to realities that are beyond the purview of science (which is, as Kant has it, just about the “appearances”, not “things-in-themselves”); and, that such notions may lead to misleading characterizations of reality, like that all things may be reduced to elementary parts interacting in space and time and that, furthermore, all understanding of nature must presuppose such a conceptual reduction. In a sense, all that the structuralist philosophers of recent days are saying is that ‘substance’ or ‘essence’—ontology in the sense in which analytic philosopher have used the term—needs to be generalized in order to account for new physics and new experiments, and that ‘substance’ is not a notion that stands outside this empirical endeavor nor is it an attempt to grasp the “nature” of reality. That is, when it is said that “structure is all there is”, this is a radical thesis only insofar as it is taken to be a claim that “reality is ultimately composed of structure”, but it is a relatively conservative thesis insofar as it is taken not to be a statement about the “ultimate nature of reality” but rather a statement that entities (whenever studied empirically) are just relational structure upon deeper analysis—and there is no end to this structural decomposition (as it were).

Notice, that as I've construed the whole issue, one does not have to show that metaphysics, as the study of substance, essence, etc., is absurd or wrong or that it should be avoided. Rather, it just puts metaphysical—I would say, "ontic"—speculations in the service of empirical inquiry, and not the other way around (this is the thesis, indeed, of Ladyman *et al.*'s "polemical" introductory chapter). As for a study of "Being as such"—what I would call "ontology" proper, and what is usually called "metaphysics" proper—that is certainly an important endeavor, but it is one that is not directly relevant in the construction of scientific theory or experiment. It *is* relevant, though, when it comes to fundamental questions concerning time, and our experience of it, and *this* sort of questioning becomes the fertile soil from which truly insightful scientific work often springs. You cannot separate human experience from metaphysics proper—a study of Being as such—but it is often our drive to depart from our single human experiences that is the backbone of science (the ideal of objectivity).

As I understand it, then, structuralism wants to be reflective about what is scientifically known without slipping into what I have called an ontological enquiry; but it wants also to be able to accurately describe the *whole endeavor* of science itself, and to come to some understanding of scientific knowledge that is sensitive to changes in what is known without having significant and unbridgeable discontinuities in that knowledge from one age to the next. In other words, it is important to have a coherent narrative of science in order for us to make sense of it as a human endeavor, in order for us to understand what it is that we are doing (and perhaps to give us an inkling into *why* we are doing what we're doing).

In this light I offer the following thesis as to what science is "about":

Within each relatively well-defined and well-understood domain of application, a science is in the business of giving us a relatively good and accurate description of what we can call the "modal structure" of each domain of phenomena; it gives us ways of manipulating and intervening into that modal structure (which, of course, *becomes part of that modal structure itself*). Our attitude towards the successes (and failures) of science should be that it provides us a relatively limited means of describing and manipulating the modal structure of relatively isolated domains of phenomena[27]. What we learn from science, then, is how to reliably "make things happen" and how to systematically interfere into how things go, by means of a theoretical framework which in turn enables us to systematically relate together into a theoretical whole the goings on, the interfering, and the making of things happen. It is this aspect of *theoretical unification*—the pulling together of possibly diverse phenomena under one theoretical framework—that constitutes what I will call an "ontic" enquiry: the postulation of concepts (axioms, definitions, or even explanatory mechanisms and entities), and their marriage to observation and experimentation. This we call science.

By "modal structure" I mean the relatively stable, recurring patterns of activities, and the relatively stable and recurring systems of counterfactual dependencies (which we often find as we attempt to intervene/interfere with those relatively stable and recurring patterns of nature). This constitutes an empirical

[27] It is consistent with this thesis that there may exist bridges between these relatively isolated domains, and that would constitute yet more modal structure—so-called "inter-theoretic" relationships.

structure of relationships, representable by mathematical structures to which, with the aid of fundamental concepts like ‘length’, duration’, etc. in conjunction with readily constructible material correlates (like ‘meter stick’, ‘laser beam’ or ‘clock’), we ascribe what we call measureable, “physical” quantities. These numbers, in turn, reflect our mathematical representations, and must have (at least in principle) clear relationships to physically observable/detectable, reliable and regular material situations[28].

Notice that I am taking a particular view about science, and in so doing it may seem that I lapse back into what I called an ontological enquiry, where the presupposition is that there is some ontological truth behind the object of enquiry to which my study is directed—which would be a confusion on my part. Such is not the case. When I speak about “science”, and advance a view as to what it is “about”, it is not inconsistent with the general view adopted here that we take this thesis to be just another empirical hypothesis that is open to being epistemologically correlated with the facts. But what are the facts, you may wonder? Here, we enter a kind of anthropological, sociological and historical domain of enquiry. By ‘science’ I simply understand a particular tradition and method of conjecture and experimentation that has given rise to several successful and fruitful theoretical systems, systems which are relatively fixed in the historical record.

Curiously, there seems to be a disturbing theoretical and conceptual *regressus ad absurdam*, looming in the background here, for it seems to be implicit in the

[28] However, as is the case with the infamous “measurement problem” of quantum mechanics, this relationship sometimes threatens to break down.

position I am stating that in order to understand anything at all, some conjecture must be advanced for it, and found to either epistemologically correlate with the facts, or fail to (in which case the conjecture is let go of, and the processes begins again)—including notions such as 'fact', and so on … *ad infinitum*. Here you might think that the notion of ontological Truth might actually do some good, that it provides a kind of wall, or at any rate, slows and greatly limits this simultaneous calling into question of everything, which includes the very grounds of questioning itself. But this problem is only an appearance, a pathology of thinking, we may say; there really is no problem. It is only a problem if you think that understanding and knowledge are inextricably linked, and that either requires a complete explication of that in virtue of which the concepts of understanding or knowledge are true. This is not the case.

Firstly, I distinguish knowledge proper from understanding; the former is grounded in systematic theory and ends in a coordinated system of some sort[29], the grasp of which constitutes, by definition, knowledge in full, whereas the grasp of a part of it (on the assumption that the whole is true) constitutes (again, by definition) knowledge in part. But like a musician who has grasped either a whole or part of a theoretical musical system, there needn't be present in him a grasp of that system in terms of an explicit *conceptual* grasp of that system. Rather, knowledge of a system may be demonstrated in his understanding, which is more general in nature (comprising the movements of his muscles—what we could call "somatic" understanding—in addition to his being able to articulate specific concepts and their

[29] We may call this the *highest* aim of science—something like what Aristotle tries to achieve in his *Physics*, but which had to be overturned given the failure of his basic notions to correlate with the facts dictated by a new view of the universe developed by the line of natural philosophers from Oresme, Galileo, Kepler, to Newton.

logical connections). Thus, understanding is rooted in the actual being of a person, whereas "knowledge" is objective in the sense of being a coherent/consistent collection of propositions (that may be said to be "learned" or "taken in"), which, in their turn, may or may not epistemologically correlate with the relevant facts (here—and only here—I take science to be the *only* source of knowledge proper).

As knowledge in the sense we use here is itself going to depend on the *specific form* it is given (where that means its specific conceptual/intellectual *representation*), such knowledge will be dependent upon many contingent things, like, choice of logical axioms or postulates, physical concepts, etc.—all of which, to paraphrase Einstein, are free inventions of the human intellect. But since we have abandoned the correspondence notion of truth in regard to this conjectural mode of enquiry (which we call science), the need to clarify or analyze some notion or other which that enquiry requires is not problematic, for the simple reason that its aim is to become epistemologically well correlated with the facts. Perhaps our very notion of 'science' itself might have to be called into question—and this is left as a viable possibility.

Perhaps, too, our notion of 'fact'? Here we come to a crucial question, which concerns the foundation of this conjectural enquiry, the asking of which threatens to render the whole view advanced here incoherent. But we may easily answer this quandary: 'fact' is partly a function of the theoretical domain that seeks to correlate its conjectures with those facts—the two cannot be neatly separated. Inasmuch as theory (and so also what 'fact' is) depends on a free invention of the human intellect, and inasmuch as we have relegated ontological truth to a separate domain of enquiry (the purely metaphysical), and insofar as we take science to proceed tentatively, then our problem of a regression to absurdity is really a fiction, conjured on the basis of premises which we are rejecting (the problem is more a question of ontology, and so is unfair to judge the merits of our present thesis by its standards). To put the point differently: if 'fact' is restricted to a question concerning the "essence" of fact, the nature of it, then even more clearly is this a question that is ontological (and not properly 'ontic'), and which, in the probing of the question, leads inevitably to a question concerning a "mind-independent reality"—all of which, as I've said, are, properly, ontological questions, and these questions do not concern us here. Nonetheless, there is a perfectly clear and cogent sense of a question concerning 'fact', and that is the extent to which facts and our theories are intertwined. Sometimes a theory might require a revision in what counts as a fact, on the basis of a new theoretical system. I take it that the switch from the Aristotelian view to the Newtonian one entailed just such a switch (in a perfectly clear and specific way—which is not a question relevant to, nor to be considered from the point of view of ontology proper, a question concerning truth and being as such).

In a way, the distinction I am drawing here corresponds to so-called "internalist" (coherence theory) vs. "externalist" (semantic or correspondence theory) notions of truth—but the similarity does not go very far, for such a distinction between theories of truth presupposes an investigation into (or analysis of) 'truth' as such, that is, it concerns itself with 'what truth is'. Nothing like that is implicated in my present discussion; *all* of such concerns are, according to the position adopted here, to be relegated to the properly ontological domain of enquiry[30].

Our concerns should rather be directed to what is meant by “epistemological correlation between conjecture and fact”, as this relation supplants our concern for “truth” as in “correspondence of the proposition or idea to an ‘external reality’” (having, of course, rejected the view that science consists, essentially, in scientific theories viewed as *collections of propositions or atomic statements*[31]). We turn next to this issue, as it will be of fundamental importance to my overall thesis.

I borrow this epistemological idea from Einstein, whose reflections on physics and philosophy (epistemology really) are often overlooked or misread. Before I turn to Einstein’s treatment of this idea, I want to remark about the character of the relation in regards to two general types of conjectures, one we call simply a “local conjecture” and the other we will refer to as an empirical postulate, axiom or perhaps

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[30] I think there is only a singular answer to that question, for which a “theoretical account” in the sense of logical analysis is inadequate (possibly confused), and that is “truth is Being”.

[31] That is, I reject both the “syntactic” view of theories, and the “semantic” conception, inasmuch as these conceptions are meant to explicate what a theory *is*, or what the *nature* of theories *in general* is. I do not subscribe to such a flat-footed monism, and treat either view as partial and tentative. My own view is that if the distinction between the two, roughly, amounts to the distinction between theories as sets of propositions (axioms and theorems) vs. collections of models (Monton 2008), then it seems that *both* views constitute together an accurate *description* of theories as we have come to know them, and as working theoreticians use them. Again, even regarding the question of theories, we are engaged in a conjectural enquiry (according to the general philosophical position advanced in this dissertation). However, it has become commonplace for most academic philosophers of science to take a second-order, “philosophical” approach to the analysis of concepts—such an approach I say is confused, if taken to be an ontological pursuit; if, rather, we take it as an “ontic” one—a matter of empirical enquiry (science)—then we take it to be by its nature conjectural. Thus, I am at liberty to marry the two conceptions of theory as each case may require. (I am also, by the way, rejecting the view that in order to even call a theory a ‘theory’, one must advance a general account of the term ‘theory’, that in order to know what a theory is—what scientists have done for centuries—one must have a fully explicit theory of theories in place, or that there must be an implicit system of rules that may be made explicit in virtue of which a theory is a ‘theory’. Such questions *are* perfectly valid as an anthropological or sociological or even a purely linguistic matter (the use of terms, grammars, etc.); but as scientific questions, they are, as I’ve said, *inherently conjectural*.)

simply, “principle”. The former sort of conjecture stands alone, and invokes a theory in order for it to be applied to a physical situation that constitutes its test.

A “local conjecture” may be a singular statement, but is often more of a collection of statements that suggests a model-explanation of some physical situation that is under investigation. The germ theory of diseases, for example, constitutes a conjecture of this sort: the postulation of the existence of microscopic organisms (with their own causes and conditions of growth) that purports to explain the manifestation of a disease or collection of diseases. This theory, as it is corroborated by the relevant facts, will in turn be folded into a larger theory or theories involving the fine structure of the microorganisms themselves, which can then be related to theories of human anatomy, metabolism, and so on—and thus we build to a larger theoretical picture of disease that involves the human organism and the microorganism in a larger dynamic whole (a kind of symbiosis). We may, in its turn, fold this understanding into a more general theory—say, evolutionary biology and genetics—in order to understand how the microorganism, over larger periods of time, evolves in relationship to the drugs we might use on the human organism to destroy, or interfere in the life-cycle of, the pathogens we have been able to isolate.

Local conjectures—like the germ hypothesis and resulting theoretical model it suggests—are different from conjectures we are calling postulates, axioms or principles. These are of a general character (like the principle of biological evolution, or the principles of classical thermodynamics) and are often *not themselves strictly testable but become part of the very constraints on any particular, local hypothesis in its domain*. In other words, they will often function as regulating principles on the *sorts* of local conjectures that may be advanced. Inasmuch as any *particular* experiment may potentially call into question the specific assumptions it makes, including the local conjecture for which the experiment was fashioned and the assumptions required in order that the experiment itself may be built, any particular experiment always implicates the entire theoretical paradigm under which it is subsumed (this is Quine's theory-experiment holism). And so we may say that, in general, it is not possible to "isolate" as general a conjecture (we call it a principle) as the light principle (for example), or the prohibition of perpetual motion machines of various sorts (the context of the first and second laws of classical thermodynamics). Rather, such principles may be overturned only given a conceptual counterexample, or else be overturned on the basis of another set of conjectures which is more fruitful (for example, Einstein's theory of special relativity is of the second sort relative to its aether theory rivals, which in turn presupposed principles of Newtonian physics[32]).

[32] And here I would say that Einstein's theory did not overturn *as false* its rivals (aether theory or otherwise); rather, it merely proposed simpler postulates from which simpler explanations for the apparent incompatibility of the laws governing electromagnetic radiation and the principle of relativity followed (that problem for which Lorentz offered a more complicated program, one of deriving the right form of the laws from a consideration of the mechanical forces exerted on an electron's orbit in motion relative to absolute space). Since an overturned theory is not "false" (strictly speaking, it still may manage to correlate rather well with its facts, given a sufficiently restricted set), nor an accepted one "true", it would be wrong to deduce consequences from theories that are taken to be about the "nature of reality". The conjectural nature of science demands humility here, rather than metaphysical extravagance. Nonetheless, our theories do lead us to new ways of thinking about reality, *which may in turn becomes facts that we must live with*. I am thinking of the possibilities of time travel that General Relativity implies, or the minimal sort of holism that some take as a consequence of the quantum superposition principle: they may certainly make us see the world and our experiences in a different light, but until they become actual features of the experiences of human beings (upon which we would have occasion to reflect), they are strictly of a conjectural-theoretical sort, and have little to do with our human *understanding* as such (recall the distinction I made between knowledge and understanding). I say "until": I take it that there is no radical or permanent dichotomy between what Sellars has called the "scientific" vs. the "manifest" view, and that it remains to be see what consequences of our theories may become elements of human experience, and hence made "manifest" to us. Reflections of this sort may be found primarily in works of literature and poetry (art in general). For example George Gamow's works, though not of a strictly academic sort, raise the sorts of questions raised here (interestingly, Hans Reichenbach, perhaps somewhat unwittingly, reflected on this sort of thing in his well-known study *The Philosophy of Space and Time*, p. 138—139, where he considers the issue of

The distinction I have drawn between local conjectures and principles corresponds to a large extent with the now famous distinction Einstein liked to make between theories of principle (like special relativity and classical thermodynamics) vs. theories of a "constructive" nature (like the kinetic theory of gases). I have not employed this distinction exactly as Einstein used it, and it has come under some scrutiny recently (i.e. by Prof. Michel Janssen), but I do see there to be a deeper epistemological and methodological lesson here, and that is one having to do with the nature of the conjectures central to either sort of theory[33].

When Newton proposed his theory in the *Principia*, it was largely on the basis of a series of principles, which in turn allowed for a large collection of local conjectures to be formulated (all manner of mechanical theories resting on his principles of motion), keeping natural philosophers busy throughout the 18th and 19th centuries. In contrast to the approach of his rivals (namely, Descartes and the so-called "corpuscular" school of natural philosophy), Newton proposed a theory of universal gravitation that did not attempt to build up the phenomenon from independent units carrying mechanical force which, only in concert, would constitute gravity (e.g., the famous "vortex" theory of the Cartesians). Nonetheless, Newton, as well as most other natural philosophers of his day, proceeded in an "axiomatic" fashion, which involves the stipulation of general principles (axioms or laws of

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time order, and what it would be like, from the point of view of an observer on what he called a "closed causal chain". I think his considerations raise interesting questions about the unity of consciousness along causal loops, and what an 'individual being' is that could meet itself at different times).

[33] Obviously, as to whether or not the distinction between principle and constructive theories is itself tenable, or as to its specific merits, I do not here propose to say or consider; I simply find it useful to some extent.

motion, as Newton termed them). Newton succeeded simply because his principles were of the most general sort, the most universal in scope.

It becomes an interesting epistemological question as to how exactly these principles may be *justified*. It is an interesting historical fact that while his axioms and definitions are not entirely clear, or sometimes seem to be circular, the theory led to a great many successful applications in the next two centuries of its use, expanding its domain of application considerably. On this, Dijksterhuis writes, therefore, that

> [p]roperly speaking, the whole system can only be understood in the light of the subsequent development of the science. But even then it is still difficult to discover Newton's precise intention in every case, and consequently many differences of opinion have persisted to our own time about the meaning of some of his statements (1961, p. 466).

So, we cannot treat the question of the justification in too strict a fashion (i.e., as a matter of deductive logic), since the general principles need only to be consistent with the phenomena they purport to cover, and to form a self-consistent whole themselves, even though the specific meaning of each statement individually considered may not be entirely clear[34]. We may take these as minimal conditions, and not conditions for the *truth* of the principles—only for their *initial* correlation with the facts and for the theory's internal, rational coherence (this last condition of which may not at all be necessary in any important sense[35]). Once such a conjectural system passes those minimal conditions, it may then be used to derive consequences that may, in conjunction with other assumptions or local conjectures (i.e., ones attuned to

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[34] Indeed, there may always be an ineliminably "tacit" component to what is expressed in any axiomatic formulation of any science, in mathematics and well as in physics (mechanics). This was a topic of interest for Polanyi, for example (*see* his 1974 book *Personal Knowledge*).

[35] Some have argued that inconsistent theories were, and might still be, scientifically acceptable or useful.

a more limited domain of application, say to hydrodynamics or collisions between massive bodies in motion), be tested experimentally.

Having made the distinction between local conjectures and general principles sufficiently clear, we then must pass on to what I mean by "empirical correlation" between conjecture and the facts relevant to that conjecture. Our ultimate concern is what the nature of the ontic commitment is regarding the structuralist about science, i.e., we want to know: "what is it" that one thinks science is "about", if one is a structuralist?

We have already distinguished between two separate modes of enquiry, the one properly called "ontological", and the other I have dubbed "ontic"[36]. With ontic modes of inquiry we study beings in their individuality, and seek to inquire into their specific natures; here, we put forward conjectures of various sorts (local hypotheses and general principles). With the ontic mode, it is a *presupposition* that there is a reality to be inquired into—the act of looking and posing questions about particular beings is proof enough here (should we cite Moore's infamous proof?). As such, this presupposition, inasmuch as nothing further of it is required in order that particular beings may be studied (just that *they exist at all*), is entirely trivial and vacuous regarding ontic enquiry as such. It may be tossed aside. It was only on the assumption that there *must* be some clear *connection* between an "external" reality and those propositions of science that make a coherent science possible—it was only on account of *that* assumption that we had to worry about "reality" as such (its existence), and

[36] Though I haven't bothered to use that term much; this is so that we do not conflate the general domain of enquiry I have called "ontic"—basically, empirical research into the nature of particular beings— with another position which is called ontic structural realism.

whether and to what extent we could have true or justified knowledge of it. The ontic pursuit is one in which we always begin with a *conjectural* specification of the nature of particular beings (perhaps even occasionally calling into question what the nature of the 'particulars' are that are under study, and whether or not a refinement of that concept is called for[37]), with the perpetual understanding that it will be overturned in light of new facts or theories. It is not the "nature of reality" as such (a reflection of the "eternal truth behind appearances") that we are discovering; rather, we are uncovering relatively well-corroborated empirical relationships that exit. We may say: what we are learning about the world is what conjectures constitute relatively stable correlations with the relevant facts—*specific conjectures* being our way of rationally knowing reality[38]. Whenever a conjecture does manage to reliably correlate with the relevant facts, we may call that an "epistemological correlation", after Einstein, as pointed out by Northorp in his analysis of Einstein's conception of science.

[37] One simple way to understand "ontic structural realism" is just this way: a proposal that a richer and more sophisticated notion of 'individuals' is called for, possibly (for example) by both relativity and quantum mechanics. That is, rather than worrying about the nature of individuals per se as a strictly metaphysical question, we worry about whether we can coherently extend the notion in a particular theoretical context to account for seemingly anomalous findings, like the issues raised by particle label-swapping in quantum statistics. (There, thus, is a kind of metaphysical underdetermination (see Ladyman and Ross 2007)).

[38] Recall that I have made a distinction between knowledge and understanding; accordingly, scientific knowledge would not exhaust understanding. Nonetheless, the only valid knowledge would be scientific knowledge, where 'valid' means 'epistemologically correlated to the relevant facts'. In a sense, just about *anything* may constitute scientific knowledge (inasmuch as there is a theoretical component to it, which itself is, to borrow again from Einstein, a free invention of the human intellect)—"let a thousand flowers bloom", as Feyerabend once remarked (quoting Chairman Mao). But that some conjecture gets to become an element of scientific knowledge depends on the extent to which it correlates to the relevant facts. Something like astrology, for example, may simply be beyond a true test *qua* science in our sense, i.e.: the experiments it would take to discover whether the facts correlate with its conjectures may be beyond our present abilities, or—and this may be more reasonable a judgment—astrology just doesn't have nearly a general enough theoretical *form* (formulated in terms of principles that relate the actual motions of heavenly bodies to the births and lives of individuals) to make testable predictions. We make no pronouncement as to whether such a thing is somehow inherently impossible—nor should we ever try to demonstrate a claim of such obviously impossible generality.

4. Summary of the proposed position. In summary, there are two major changes to our orientation towards the fourth tradition that the position I am developing here entails.

I am proposing a change to the nature of the *second-order presuppositions* of the fourth tradition, and, on the other hand, I am suggesting that structuralism can be understood as a methodological program for the doing of science itself (i.e., it is also a *first-order project*). Here the thesis is that the fourth tradition may actually *constitute a part of science*, rather than being a merely second-order, normative project. I would like to show that this methodological program of structuralism is already working in physics itself: we can see it in both the switch from Newtonian to relativistic physics (as Einstein envisioned it) and in the switch from Newtonian or classical physics to quantum mechanics. It is a program that has as its central element the removal of the criterion that scientific/physical explanation must presuppose a description of either matter in motion, or self-subsistent entities with intrinsic properties that "cause" or "bring about" certain effects (which will themselves be characterized in the same ontic terms). According to structuralism, physics is the search for invariant mathematical structures that may be applied to nature *irrespective of the material constitution* of that to which the structures are applied. The structuralist, furthermore, says that even the *material constitution* of an object of physical investigation will be understood structurally. The structuralist, therefore, is committed to the idea that the notion of an 'object' is derivative from structure. Beginning with a roughly individuated, well-localized, relatively independent 'object' (say, an atom) of study, physics subjects it to a theoretical scrutiny to learn its properties. The thesis of structuralism, *qua* methodological program, is that upon this further analysis, the ‘object’ under study will be just more structure. More particularly, the thesis here is that ever since both relativity and quantum theory, physics has discovered that there is more relational structure to nature than previously thought, and that the idea of an independent, self-subsistent entity evolving against a background spacetime in terms of which all features of nature may be explained was too naïve a picture, and that particles of matter are like self-contained, relatively independent, permanent/continuous objects akin to the macroscopic objects of everyday experience is mostly inapplicable in both the relativistic and quantum regimes.

As has been noted by many philosophers of science, there are no “pure observations” (ones sealed off from any theoretical presuppositions of a more or less scientific sort), just as there is no “pure theory”. Any time a conjecture is put forth to be tested against experimentation, we bring to the table some understanding (however rough) of how the theory and the experiment itself are linked, and what it is that is going into the experiment, and what it is that comes out—all of this is established by traditions of experimentation and observation that any experimentalist has been steeped in (implicitly or explicitly). More importantly, a crucial aspect of theory confirmation is the *interpretation of the data*. Fundamental to any interpretation is some way of coordinating the results into a sensible whole, and fundamental to *that* are certain basic categories and distinctions: system, subsystem; experimental apparatus, object of experiment; space, time; mass, momentum, energy, and so on. A very fundamental category of thinking about the world is *individual*, and *object*, and we usually tend to think of these as entities *bearing* certain *properties* or physical quantities (charge, spin, mass, etc.). When we do science, these fundamental categories become very important to our interpretation of the data to which we hope to successfully correlate with our conjectures. These categories help the scientist to do science with more understanding; they help to orient the scientist in the world of theory and experimentation by answering the question: *what is it that is being studied?* But in doing science, we are opening up our fundamental categories to a kind of test; we ask of them *can they be successfully extended to such and such a theoretical domain?* Occasionally, the confrontation of conjectures with experiments requires abandoning some fundamental assumptions that perhaps were hidden in the science one was working with, and which, when made explicit and finally overturned, might very well lead to a an entirely new theory, which, in its turn, will lead to new ways of thinking about the world—and so the process goes, century after century.

The thesis being developed here argues that we are not overturning as *false* prior theories or prior ways of thinking about the world; rather, we are giving up what were always tentative conjectures about the world that proved not to correlate well with the facts (which of course leaves open, in principle, the possibility that *older* ways of thinking may very well return someday in the future). I propose that structuralism can be understood as offering a more general way of thinking about the world that is relevant to the act of making conjectures about the world, and so may be considered part of the doing of science itself. Structuralism (what I will call "ontic structuralism") proposes that it is coherent to think about reality in terms of relational structure, rather than primarily in terms of individual entities (changing with respect to a background, independent spacetime). This is, as it turns out, exactly what Lee

Smolin (2000, 2006) is considering as part of his overall attempt to resolve the so-called problem of "quantum gravity". I propose that this is a *first-order* example of structuralist thinking that argues for a different conception of what fundamental physical reality is like, which also has the potential of becoming a new fundamental physical theory. It is part of Smolin's proposal to actually *derive* spacetime itself from more fundamental structures, out of which, in turn, entities such as well-localized particles arise (they are called "knots" in his theory). Here, structuralism is simply a way of making sense of a theory in which there are no entities "at bottom". I am arguing that, in other words, *ontic* structuralism *is a conceptual aid in the putting forth of conjectures of theoretical physics, rather than a conclusion* from *such endeavors*. Such a point of view must be considered admissible, for the simple reason that the task theoretical physics sets for itself in this case is to find *laws governing the origination and evolution of spacetime itself,* on the basis of more fundamental structures (called "loops").

Aside from the change in the presuppositions in the whole debate surrounding the main contentions of the structuralist (the fourth tradition) that I have outlined (changes which are largely negative, or, we may say, *destructive* of the Kantian tradition that frames any talk of 'realism'), I want to offer a more *positive* second-order framing.

It is the hallmark of science that it aims for the greatest generality in its given domain of inquiry. Even if that domain be itself narrow, or there be a kind of patchwork of relatively autonomous domains, still the hallmark of science is the coordination of the beings in its domain (however autonomous in respect to other domains of beings) by means of general principles.

We may call into question, though, the tenability of this claim about science's generality. Perhaps it is unwise to conceive of science as aiming for greatest generality—perhaps the universe will simply not admit of that. My reply is twofold: the universe will not rule on an ontological question one way or the other, as, in accordance with the view advanced here, such implications from a scientific theory are *never appropriate*. Science will not "reveal" to us that our universe is "dappled" or "patchwork", for example[39].

Secondly, and perhaps most importantly, the issue is understood as primarily epistemological, and here is where the structuralist has something positive to offer: there can be no true scientific *understanding* on the basis of scientific knowledge unless it is possible to coordinate the whole of that knowledge *into a unified system*. I will have occasion later to defend this rather brazen claim[40], but suffice it here to say that what the structuralist also offers is a view which meets such an adequacy condition, insofar as structuralism is understood as the view that all there is to the world is structure, and that independent entities are themselves more relational structure upon further (empirical) analysis. This means that *nothing is truly independent from anything else, inasmuch as both share the same world*. This must be understood as an ontic claim that allows for the satisfaction of a greater

[39] Even if we have reason to take such a view—which we might, to be consistent with the openness of science central to my thesis—such a view would amount to *yet another conjecture*. And even here, such a view is independent of the epistemological thesis I outline in what follows.
[40] It requires a reconsideration of the distinction I drew between knowledge and understanding, and will also involve a discussion of Sellars' distinction between the scientific vs. manifest views, among other things (*cf.* his *Science, Perception and Reality* [1963]).

epistemological desideratum (that of *unity of knowledge*). So we arrive at a kind of normative or regulative dimension of structuralism: that it is the conceptual mechanism by which an epistemological unification is made possible, and which builds on an ontic claim about the nature of individuals.

It cannot at this point be said that structuralism is the *only* conceivable ontic point of view that enables this unity of knowledge, but it is certainly plausible. Since it is the nature of ontic structuralism to entail as a consequence that *there are individuals* (they are just not basic entities or "simples"—*they are derived*), and since the relative boundaries between one class of individuals and any other is in principle open, it is possible in principle to arrive at a view in which each domain implies all the others, and so we would have a real unity (as opposed to merely a logical or abstract one). By 'real' unity I mean, simply, that the beings of one domain theoretically implicate (by virtue of their structural nature) *all* the others, rather than simply relate to the others by means of a purely logical relationship (like that of "supervenience" or "being next to"—neither relations of which involve the being of one domain in the being of another). But this can only be, so far, an ideal to which we might aim our sciences, the hope being that as our sciences become more sophisticated, and that their principles become more general, it is possible, in principle, to map the empirical relationships from any one being to all the rest, thereby providing content to the structuralist claim that even individual entities are just more relational structure (the implication being that even the *domains* of individual beings—that is, the domains of individual sciences—will themselves prove to be as relationally rich as the entities themselves).

Chapter 2: Scientific Explanation and Structural Realism.

Explanations in science, in actual practice rather complicated, essentially break up the world into two parts and attempt to reveal some kind of link between the two which, depending on the strength and form of that link, is said to be explanatory. For example, take the famous case of the perihelion of the planet mercury. The problem, put simply, was that the actual observed orbital trajectory and speed of planet Mercury differed significantly from that which a simply application of Newton's theory predicted. By taking into account an additional physical consideration that had eluded classical theorists—that the sun not only provides an attractive force on Mercury on account of its substantial local mass, but that this mass in turn alters the local geometrical structure (i.e., the local spacetime around the sun) such that the equations of motion for any object in its vicinity are likewise altered—Einstein, using his newly discovered field equations, was able to calculate the exact elliptical path that will be taken by Mercury at a given (known) distance from the sun, and was able to provide a formula for its orbital period (in radians per revolution; cf. Einstein (1922/2005), pp. 92-97). This proved to be in accordance with what had been known about Mercury's orbital period from observation; thus, Einstein's theory was corroborated and Mercury's orbit was explained. The sense of explanation in this case seems to be rather clear and straightforward at first glance: planet Mercury's orbital trajectory (given by the relevant equations of motion) and period follow directly from Einstein's Equations, plus the appropriate idealizations, physical constants and known values for the respective masses of the sun and planet Mercury. The phenomenon to be explained (the orbit and period), which we can call the "explanandum", follows from a mathematical law of nature (Einstein's Equation), which we may call the "explanans". But so far, we only have solid grounds for believing that we have a very good description—as good as the fit between the observed data and the predictions of Einstein's Equations. We are able to calculate *that* planet Mercury has a certain orbital path and period, and can see that this is more or less confirmed by looking at how the planet actually moves. But *why* does it move along that path, that is: in virtue of *what* is the path and period what it is? We are asking to have the relationship between the explanandum and the explanans developed in more detail in such a way that we may say that the content of one "explains" the other on account of some deeper analysis, and that the whole thing is more than *merely a description* of what can be readily seen and measured.

It is certainly true that the phenomenon, in virtue of the fact that it can be subsumed under a general law of nature, can be *predicted* on the basis of knowing a few physical constants and the masses of the bodies in motion, which in turn trace out a certain regular and observable trajectory in space and time. But this only seems to tell us *that*, rather than *why*, something will occur, and surely it seems odd to say that *because* the phenomenon is subsumed under a general law of nature, it will trace out a particular orbital path with a certain speed.

We do not need to rehearse the well-known objections to the deductive-nomological view of scientific explanation[41], but it is enough to mention that showing that a certain phenomenon can be subsumed under, and therefore be predicted to

[41] *See*, for example, Salmon (1984) for a detailed analysis (Salmon rules out the DN view in favor of the Causal-Mechanical view, which we will discuss below), and Woodward (2003) for a brief overview.

occur on the basis of, a general law of nature is not sufficient for its being *explained,* at least not in any interesting sense of that term[42]. It seems, at least to some, that more is required for an explanation to go beyond mere description. How much more and what the 'more' is, so to speak, is now going to depend, crucially, on what you think the right explanatory resources are. You have to now make a certain *normative* judgment about the proper *form* that explanation will take, one that inevitably will either (1) take a certain metaphysical position, involving ontological choices, or else (2) attempt to *avoid* metaphysical commitments altogether, or at any rate be neutral with respect to them. This seems to be the basic decision tree for providing a scientific explanation of phenomena, and there have been several theories of explanation cooked up to meet the demands of this tree[43]. Since the structural realist, in particular the *ontological* structural realist, has very definite things to say about metaphysics (that is, it has some definite things to say about entities and individuals, and how best to understand 'causation'), it would seem that the structural realist is going to have some very definite, perhaps surprising, things to say about scientific explanation. This section is going to explore exactly that question, namely, *what does the structural realist have to say about scientific explanation?*

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[42] And here I basically side with Salmon (1984), who argues, briefly, that no explanation is satisfactory, or robust, unless it appeals to some feature of the world in virtue of which the explanans *explains* the explanandum. The D-N view presupposes that explanations are arguments, and so in this sense it is an "epistemic" form of scientific explanation (Salmon 1984, p. 121). This is to be distinguished, according to Salmon, from the "ontic" variety such as the Causal-Mechanical view. This view (which Salmon tries to defend comprehensively) appeals to the causal structure of the world (explicated in terms of casual connections and interactions) which may be used to determine or otherwise produce the explananda. Thus, the link between the explanans and the explananda is about a feature of the mind-independent structure of the world and not about logical entailment as such (which is what the D-N view presupposes).

[43] Obviously, I'm taking the view that a theory or general account of scientific explanation is cooked up to meet the needs of certain phenomena, or classes of them, that are taken to require, or are otherwise plausible candidates for, a scientific explanation. The order clearly needn't be like this.

1. The causal-mechanical view and "explanatory realism". Rather than constructing a general decision tree of possible explanatory models and the metaphysics associated (or not) with them, we will simply work with a popular model of scientific explanation and one that may at first glance appear to be *opposed* to the metaphysics of the structural realist: the causal-mechanical view. From this we can work out a rich enough problem space for the structural realist to consider, and see what they[44] might have to say.

Each term in its title—the causal-mechanical view—is problematic, and has received much attention by philosophers of science in the past four or so decades, stemming in large part from the seminal work of Wesley Salmon (1984 & 1989). There have been a slew of very recent attempts to analyze 'causation', focusing especially on whether or not Russell was right to have pronounced it, in an oft-cited essay of 1913, a dead concept in physics[45]. In addition to this, there has been recent renewed interest in the viability of 'mechanism' as a fundamental unit of scientific explanation and understanding, especially in the biological, neurological/cognitive and medical sciences (though the issue in physics has been more or less sidestepped, largely because of the problems such a view faced by quantum theory[46]). The renewed interest in mechanism stems mainly from a now well-known piece by

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[44] Note that when I say 'the structural realist', I mean, basically, what *my* structural realist would say, not what any ("archetypal") structural realist would say.

[45] The edited volume by Price and Corry (2007), for example, is largely devoted to this general question, and many authors reconsider both Russell *and* Hume, the grandfather, we might say, of "causal skepticism". We should note in passing, though, as Salmon pointed out in his 1984, that Russell seems to have later receded somewhat from this dismissive stance. Nonetheless, whether or not physics needs the concept, and what, if anything metaphysically defensible, the concept refers to, have been problems for recent analytic metaphysicians and philosophers of science. Woodward, though, has a rather balanced view on this score in a paper (delivered in for a causation workshop in Pittsburgh, PA, on 26 January 2008) called "Causation with a Human Face".

[46] See Salmon's numerous provisos throughout his 1984.

Machamer, Darden and Craver entitled "Thinking About Mechanisms" ("MDC" 2000). Much of the fallout from this article has resulted in a fair amount of sophistication regarding the previously denigrated or mishandled concept of 'mechanism'.

It's not my intention here or in this dissertation to wade through these issues systematically, as philosophically important as they might be (we will, however, return to some of them later on). Rather, my intention here is to focus for the moment on the issue of explanatory *realism* and the causal-mechanical view of scientific explanation[47]. Despite the subtleties involved in each of the terms 'causal' and 'mechanical', the philosophical pull towards the causal-mechanical view of scientific explanation has to do with the desire to provide a deep, *realistic* account—an explanation—of aspects of the physical world, from the subatomic and atomic realms up to the biological and beyond, and to also inquire as to how these various realms relate[48] to each other (theoretically and/or ontologically). Explanatory realism and realism about scientific theories go hand in hand: those *features of the world* that, as a realist, you take a theory to be about will, at least in principle, provide the resources with which to provide, in turn, a realistic explanation of phenomena. You can explain relativistic effects on moving bodies in spacetime by appealing to features of the

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[47] Jaegwon Kim (1987), in connection with Salmon's work (1984), specifically speaks in terms of "explanatory realism".

[48] See, e.g., Silberstein (2002) for a thorough discussion on what form that relation might take. In particular, the relation may be construed in terms of reduction or emergence, each of which may be further distinguished along ontological and epistemic axes. As Silberstein points out, though, reductionism and emergence are not necessarily incompatible views; indeed, that they *are* compatible or not will heavily depend, as Silberstein shows, on what one means by the terms 'reduction' and 'emergence'. He even goes so far as to suggest that "emergentism and reductionism might form a *continuum* and not a dichotomy" (p. 99). We will revisit this issue again, especially when the question of "levels" and "levels fundamentalism" arise.

spacetime in which those bodies move, should you take a 'realistic' view of spacetime itself; or, if you are not going to be a realist about the spacetime itself, then you might appeal to the dynamical *forces* between moving bodies that can in turn explain where and why they move as they do. In each case, *what* you are a realist about with respect to the theory naturally comports with *the features of the world* you appeal to when providing a realistic explanation of the phenomena in the domain of that theory.

Wesley Salmon was one of the first philosophers to classify scientific explanations with this question of realism in mind. In *Scientific Explanation and the Causal Structure of the World* (Salmon 1984), he distinguishes between three kinds of explanations: modal, epistemic and ontic. According to the first: "the aim of scientific explanation is to show that an event, which at first blush looks as if it might or might not have occurred, in fact had to occur. The explanation renders the explanandum-event physically necessary relative to the explanatory facts" (*ibid*., 111). The epistemic conception, on the other hand, basically takes the view that scientific explanations are arguments (or are otherwise to be understood propositionally), and may be further divided according to how the relation between the premise(s)/conclusion(s) is understood: is it simply (a) deductive-logical entailment, is it (b) information-theoretic or otherwise statistical/inductive, or is it (c) "erotetic", that is, does it have to do with the logic of "why" questions[49] (*ibid.,* pp. 84-111)?

[49] The distinguishing feature of this latter construal of the epistemic view is that the structure of the logic is going to be ineliminably *pragmatic*. This has been the position of van Fraassen.

As for the ontic conception: "the aim of scientific explanation … is to fit the event-to-be-explained into a discernible pattern. This pattern is constituted by regularities in nature—regularities to which we often refer as laws of nature" (*ibid.*, 121). But not just *any* regularities are going to count if this conception of scientific explanation is going to be distinguishable from the epistemic and modal conceptions: only genuinely *causal* regularities will do. That is, an adequate ontic scientific explanation is going to have to fit the event-to-be-explained into the *causal structure of the world*, that is, roughly, the pattern of cause-and-effect.

Salmon takes it as his task to explore, and defend as best he can, a causal/mechanical view of ontic explanations throughout the rest of his book, after first trying to rule out both the epistemic and modal views. In so doing, he develops a variety of scientific explanation that comports well with theory realism[50]. It suggests that only theory realists would be motivated by the ontic conception, unlike, say, anti-realists or a "constructive empiricist" (i.e., van Fraassen) who aren't going to assume that you have to appeal to "features of the world" (such as Salmon's favorite, the "causal structure of the world") when providing a scientific explanation because, they would claim, theories (or the sciences in general) just aren't about that sort of thing to begin with.

Let's explore the causal-mechanical view in more detail as developed by Salmon, which is used to provide substance to the idea of "ontic" explanation. After this initial exploration, we will be able to relate structural realism to our discussion.

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[50] And so I have called this, in recognition of the close relationship between theory realism and the ontic view of scientific explanation, "explanatory realism". As with theory realism, we may take "explanatory realism" to be a certain kind of *attitude* regarding the scientific explanations.

What I would like to show is that the causal-mechanical view need not be overturned per se, but that it must be reinterpreted in light of the metaphysical lessons of physics (in particular, fundamental physics), and possibly in other areas of science as well[51]. What remains once this is done, perhaps to the chagrin of what we can call the "classical" causal-mechanist, will not be very close to the what I'll refer to as the "classical" C-M view: which (as I'll also show) is committed to at least two essential doctrines, that of "localizability" and "decomposability", in addition to (as far as Salmon is concerned) some view of the nature of causation (in terms of causal processes, interactions and 'production').

The structural realist, let us recall before moving on, provides the needed philosophical framework for the proposed reinterpretation of the C-M view, since the structural realist (on the "ontic" construal of structural realism) is committed neither to the doctrine of localizability nor to the doctrine of decomposability. The resulting view, while it might be called "causal mechanical", is, I claim, better understood as a species of what we shall term "structural explanation" (in this way we will see that 'causal-mechanical' and 'structural' are not incompatible). This version of structural explanation, as we will see, differs rather significantly from what has gone by that title in decades past[52]. Furthermore, with this structural realist reinterpretation it will

[51] There is a growing community of scientists and philosophers who employ the methods of "dynamical systems theory" to model certain aspects of nature, especially biological systems and cognitive-neural systems. I will try to show that this calls into further question the adequacy of a *classical* causal-mechanical view of scientific explanation, and suggests the kind of reinterpretation of it offered here under the auspices of "structural realism".

[52] Indeed, what R.I.G. Hughes has called "structural explanation" (actually, he draws on the work of earlier philosophers of physics like Jeffrey Bub and Allen Stairs) will be understood as a kind of "epistemic", or possibly what Salmon calls a "modal", rather than an ontic, form of structural explanation (and here I will borrow explicitly from Salmon's taxonomy, once we have provided the appropriate structural realist reinterpretation). Hughes' conception of structural explanation, which has since become the common way of understanding it, takes the position that an appeal to *features of a*

be possible to make contact with recent debates about the nature of 'causation' in science and the reconsideration of 'mechanism' or mechanistic thinking in scientific explanation outside of physics, thus furthering our understanding both of structural realism and scientific explanation. We return now to what we have called the "classical" causal-mechanical view, developed in great detail by the late philosopher of science Wesley Salmon.

2. Salmon's causal-mechanical view of scientific explanation. Salmon believes that the ontic or causal-mechanical view of scientific explanation "provides the most tenable philosophical theory of scientific explanation" (where explanation, we must recall, is understood to provide significantly more than mere *description*)—this only after the notion of 'causation' is suitably broadened to accommodate stochastic or probabilistic causation (as opposed to what we can call "strict" causation), and only after the notion of 'mechanism' is suitably modified to accommodate developments in modern physics (which, he says, provides us with "a twentieth century theory" of mechanism)[53].

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theory are explanatory in themselves, without having to provide a further account of the phenomena being explained in terms of causal mechanisms or in terms of entities, their interactions and the exchanges of conserved quantities. However, since theories are representations, or at any rate highly abstract portrayals, of the natural world, it is not clear that such appeals merit the title "explanation" as opposed to "theoretical description". Without adopting an explicit view of how these theoretical features relate to the natural world—that is, in lieu of a coherent, plausible ontology—I will dub Hughes' form of structural explanation "epistemic". It might also be "modal" in the sense that appealing to theoretical features, such as the constraints on motion implied by, e.g., the principles of special relativity, in turn "necessitate" a certain causal structure, i.e., the light-cone structure characteristic of relativity. It then follows that all dynamical equations of motion must be compatible with those constraints, irrespective of the material constitution of the bodies in motion. This is a kind of "modal" explanation in Salmon's sense (see Salmon's definition given above). It is still "epistemic" in the sense of not providing (or at least being neutral with respect to) an ontological account of those theoretical features (the "constraints") appealed to for an "explanation".

[53] Salmon (1984), p. 124.

3. The causal-mechanical view of scientific explanation and 'Humean' metaphysics.

David Lewis, one of the premier analytic metaphysicians of the twentieth century, articulated very clearly what had become (by 1986) a very widely-held metaphysical point of view in the analytic community, one grounded in the notion of "Humean Supervenience". It's worth quoting him at length:

> Humean supervenience is named in honor of the [great] denier of necessary connections [David Hume]. It is the doctrine that all there is to the world is a vast mosaic of local matters of fact, just one little thing and then another. (But it is no part of the thesis that these local matters of fact are mental.) We have geometry: a system of external relations of spatio-temporal distance between points. Maybe points of spacetime itself, maybe point-sized bits of matter or aether fields, maybe both. And at these points we have local qualities: perfectly natural intrinsic properties which need nothing bigger than a point at which to be instantiated. For short: we have an arrangement of qualities. All else supervenes on that[54].

Tim Maudlin, who has spent much of his career as an analytic metaphysician "trying to undermine" the Humean metaphysical view (as he himself said recently in *The Metaphysics Within Physics*), provides a rather illuminating gloss of it. Again, it is useful to provide a lengthy quote to focus our discussion:

> The Humean picture of ontology, as Lewis understands it, is founded on the notion of the Humean Mosaic: a collection of local quantities structured into a unified object by external spatio-temporal relations. At base, Lewis's Humean believes that this is all there is: it is not merely, as Lewis says, that everything else *supervenes* on the Mosaic, but rather that anything that exists at all is just a *feature* or *element* of *generic property* of the Mosaic. If one wants to say there are laws, for example, then what the laws are is simply a matter of how the Mosaic is structured: the philosophical problem is to specify, as clearly as possible, which features of the Mosaic *constitute* the laws having a certain form. …These sorts of philosophical analyses then count as reductions of ontology supposing (as Lewis does suppose) that the basic elements of the Mosaic, in themselves, are not ontologically dependent on either the laws or the direction of time. … The elements of Lewis's Mosaic must have intrinsic characters that depend on the

[54] Lewis (1986a), pp. ix-x, as quoted in Maudlin (2007), p. 170.

> existence of nothing else in the universe, and these elements must be related by some purely external relations, so that all of ontology can ultimately be resolved into the set of pointlike elements and their arrangement[55].

While there is no necessary relationship between Humean metaphysics and the causal-mechanical view (one might adopt the causal-mechanical view without buying into the doctrine of the Humean Mosaic), they are nonetheless obvious companions: the causal-mechanical view of scientific explanation provides a way of bridging (analytic) metaphysics to the content and method of science itself, our primary source for knowledge about what local matters of fact there actually *are*. The causal-mechanical view is a way of spinning the specific threads, as it were, of the Humean Mosaic. A vast collection of successful causal-mechanical explanations of all known phenomena, coupled with a hierarchical arrangement of all known theories of all known phenomena (in terms of the 'supervenience' relation), from "most fundamental" to "less fundamental" (call this "theory fundamentalism"), would provide a specific example of a Humean Mosaic.

Salmon's conception of the causal-mechanical view is related to the view sketched above. The basic link between the two is this: that whenever we have a successful causal-mechanical explanation of some phenomena, the phenomena will reduce to causal processes and/or interactions in the sense that the relevant causal processes and interactions, residing in spacetime, *constitute* the phenomena. In other words, there will be an *underlying* causal-mechanical process by which the phenomenon comes about and continues to exist. Thus, whenever we have a successful causal-mechanical explanation of phenomena in terms of causal

[55] Maudlin (2007), p. 170-1.

mechanisms, we may *construct* the former from the latter. But it is not enough to say that the construction is just representational or conceptual—that would threaten to collapse back into what this ontic view was supposed to avoid, which is the "epistemic" view of explanation. Rather, we must believe that the phenomena are really constituted by the causal-mechanisms; we may, as it were, unburden ourselves with the ontological autonomy of the phenomena having been successfully explained: the causal-mechanism is "what there really is", mind-independently speaking. Of course, our perception of it, and our inkling that some phenomena or other exists and requires explanation is one thing (a feature of our cognitive apparatuses, which deliver to us information about which we, in turn, theorize); but having found the causal mechanism *responsible for it* is quite another (and might, as in the case, often, in *fundamental physics*, require our giving up certain beliefs about the phenomenon, like its seeming autonomy, etc.). And this, finally, is the Humean view sketched above with, perhaps, merely a promissory note that *we may achieve a causal-mechanical explanation (and hence reduction) of all phenomena, in time*. In other words, it constitutes a general methodological paradigm in the main, and locally, a metaphysical view (i.e., about particular phenomena which have been successfully explained). It is, of course, a *further* question as to how to *relate together*, under one coordinating metaphysical/natural philosophical view, all of the cases of successful causal-mechanical explanations. This is the question, basically, as to how to relate the various sciences. The ideal Humean package is that the totality of the world—everything there is—is a consequence of, in the causal mechanical sense, the fundamental ontology (provided to us by fundamental physics). Salmon needn't be associated with such a global Humeanism; minimally, he's committed to a local Humeanism.

4. Towards a structural account of "ontic" explanation. This dissertation as a whole is an extended explication and defense of a thorough-going metaphysics of structural realism, 'structure' being understood as *relational* structure where the relata are themselves metaphysically derivative from the relational structure in which they appear (this is just to say that the relata are contextual or dependent entities, rather than being ontologically primitive or prior to the structure). Put in terms of more familiar metaphysical concepts, it is the view that self-subsistent entities, defined by the possession of intrinsic properties which in turn ground any extrinsic relations these entities bear with other entities, are metaphysically derivative from relational structure. In short, it is the view that reality is to be understood as "relations all the way down", or "relational structure all the way down". It is not a denial of the *existence* of entities with intrinsic properties; it is simply a view which ascribes *relative ontological status* to them—'relational structure', according to this thesis, being more ontologically fundamental than self-subsistent entities in the sense that the latter is derivative from the former. If we take a metaphysics of relational structure as defended here to replace a metaphysics of self-subsistent entities and their intrinsic properties, this has implications for the nature of scientific explanation and understanding.

The structural realist holds that science provides us with a characterization of the (real) structure of reality, come whatever entity-based ontology we choose to depict that structure with; the *ontic* structural realist argues that this structure is to be understood, metaphysically, as relational structure and that the 'entities' postulated for any one scientific domain are themselves to be understood as relatively stable structures which depend for their stability on certain background conditions (and so, in a literal sense, it's "relations all the way down"). Thus, entities, their properties, and the causal relations that they bear to other entities—the basic explanatory framework of science— are actually a convenient way of describing what is in reality a complicated relational structure. This stability in the background conditions makes possible our ordinary ways of talking about and carving up the world. And so we see that there is, obviously, conceptual value with, and usefulness of, the 'entity', 'property' and 'casual' language employed by a good deal of the 'mesoscopic' sciences and beyond. But when exploring *fundamental* physics, we are not guaranteed the usefulness of such concepts. And, moreover, when providing a general metaphysical view, ordinary concepts as such are just not going to do. We are not guaranteed, for example, that our ordinary concepts (entity, property, cause) will apply to realms far beyond the domains in which those concepts arose; indeed, science progresses often by *expanding* the domain of certain basic organizing concepts (space, time, entity, cause), or by *revising them completely*.

4.1 The suggestion for a broader notion of (ontic) explanation. Quantum mechanics shows that the notion of 'entity' in spacetime, and the general framework of causal-mechanical explanation, need to be profoundly revised or given up entirely. There are many interpretations of QM that show just this (and some even try to retain all or most of an ordinary, classical point of view, as the resurgent interest in 'local' interpretations of QM demonstrates[56]). But it remains to be seen whether or not a realistic explanation—that is, one grounded in a *realistic ontology*— of quantum mechanical phenomena without entities, causal mechanisms or the general framework of causal explanation is possible, one which is also not ontologically agnostic (in the manner of Arthur Fine) or instrumentalist (as with some information-theoretic interpretations of QM). More specifically, this chapter is devoted to showing what a realistic form of explanation and understanding grounded in ontic structural realism is like, and that such a view is tenable for—and even strongly suggested by—quantum mechanics. If this can be done, then we would have a *structuralist* alternative understanding of "ontic" explanation, one that is not causal-mechanical in Salmon's sense, but which is realist and "ontic" nonetheless.

The intuition behind Salmon's notion of an "ontic" explanation is that scientific explanation, in so far as it appeals to theories that can be construed *realistically*, should appeal to, or otherwise crucially depend on, *real, objective features of the world*. Hence, we may say, wherever possible, explanation should aim to be "ontic". Salmon, though, appeals to *causal mechanisms* when he distinguishes between ontic, epistemic and modal explanations: explanation is "ontic" when it appeals, essentially, to the causal-mechanical structure of the world—features that, we might add, "bring events into being", "produce" them or are otherwise "responsible" for them. The question we are exploring here is whether this construal of ontic explanation is overly restrictive; and indeed, we would like to know what

[56] See Lewis (2006), (2007) and Wharton (2007) for some recent examples.

good reasons there are for linking, as a matter of definition, ontic explanation to causal mechanisms.

As many have pointed out, to borrow from Ruth Berger, "causes are not enough" in scientific explanations, *actual* scientific explanations that hope to give us real understanding about the phenomena they purport to explain (Berger 1998). Importantly, Berger points out that non-causal features of dynamical systems are often essential components in their explanation; her example is of Dungeness crab population dynamics. In particular, she shows that you must appeal to the "one-dimensional [approximately linear] distribution of larvae"—a spatiotemporal pattern—to explain the erratic nature of the crabs' population dynamics (*ibid.* 318-9). Such a pattern is not an "event", she points out, "involving an exchange of invariant quantities at an instant in spacetime" and so clearly fails to count as a (potential) causal-mechanism in Salmon's sense (*ibid.* 318)—yet such a non-causal feature of the phenomenon being explained *is crucial*. We would like to say that such structural features (Berger's own phrasing) of physical systems are *real* and explanatorily relevant features of physical systems, and that an appeal to such features allows no less of an "ontic" explanation to be achieved. But what is *more* surprising is that, when it comes to fundamental physics, sometimes *all we have* to appeal to are structural features (for example, the existence of a physical system in a certain spatiotemporal arrangement), and almost no possibility of devising a causal-mechanical story (as Salmon often feared), as (I'd like to argue) with quantum theory. What, I ask, could underwrite an "ontic" explanation of such situations? The claim I am going develop (and defend) is that the structural realist has no problem *in* *principle* appealing to structural features of systems when providing a scientific explanation of some aspect of them. This is because the structural realist adopts the *general* point of view that what theories get right about the world is not what entities, or mechanisms there are, but rather (for mature theories at any rate) captures the right structural features of the world. However, in *specific* cases, realistic explanation of the sort hoped for by Salmon with ontic explanations, is won by only isolating specific causal-mechanical features of the world that bring about the explanatorily relevant events. This is where structural realism is obscure: what ontological features of physical systems "bring about" the events, and how are we to construe these ontological features: causally, non-causally? If the former, then how do we understand "structure" causally? And if the latter, how do we understand the relationship between the causally relevant events on the one hand, and the structures that "bring them about"—i.e., that upon which those events *are (explanatorily) dependent*. Only a structural realism that supplies a coherent ontological picture that answers these questions can provide a satisfactory "ontic" picture of explanation that would satisfy a realist (such as Salmon). If such a story can be provided, the structural realist can fill in needed ontological *details*, rather than retreat to a general, purely philosophical, point of view about the sense in which well-confirmed, but overturned, theories are true of the world. Moreover, if such details can be supplied, then we have something further to add to the notion of "structural explanation" appealed to by some interpreters of quantum theory (e.g., R.I.G. Huges, Allen Stairs and, more recently, Jeffrey Bub[57]).

[57] Such a notion of explanation is operating, I submit, in Bub's recent information theoretic

5. Structural Realism and "Structural Explanation". Realistic or "ontic" explanations in science presuppose some physical ontology by which we can grasp the details of nature, and thereby gain (we might think) true, physical insight into a mind-independent reality. However, when it comes to (at least) theory realism, the prevailing view seems to be a *realism of entities*, and we are vexed, when it comes to quantum theory, when philosophers want to avoid (or are otherwise neutral about) such a realism. We are, in particular, vexed when philosophers substitute "information" for "matter-in-motion [i.e., a physical ontology]" (Bub 2005), or characterize their interpretations by invoking "measurement" as a fundamental category, thus offending the Bell dogma ('measurement' cannot be a primitive in a fundamental theory; it must itself admit of a further theoretical/physical analysis). The vexation often stems from the underlying assumption, expressed by Salmon and Kim among others, that adequate *scientific* explanations are going to be ontic in nature, fitting the phenomena-to-be-explained (measurement, information transmission, entanglement—some now-classic items in quantum theory) into the patterns and regularities *of nature itself*. The explanatory relation is going to be what

interpretation of quantum theory. The generation of "mechanisms" capable of revealing the spatiotemporal, causal pathways between entities is quite besides the point for Bub (2005, e.g.): what it means to explain is to find the appropriate functional instantiation of an informational system, one of whose components is "information", and with this abstract specification in place, we may then prove certain quantum-computational facts about the informational system. It's not clear that a causal analysis is even relevant; and if Bub's overall thesis is right—that any attempt to provide a complete analysis of all physical processes (including, importantly, those of measurement itself) will run afoul of a general quantum information-theoretic principle ("no universal cloning machines")—then it's not even clear that quantum theory *allows for* a complete resolution of physical systems into interactions amongst its 'fundamental' parts. In other words, the claim is that is inherent in the causal-mechanical view that such a final decomposition *is always and in principle* possible; on Bub's view, the non-commutativity of QM shows that this cannot be done—or else you face a measurement problem. I look at this more closely in chapter three.

it is in virtue of *something holding between or among* things or events or processes *in the world*, and will not be merely logical or propositional in nature (the modal and epistemic views—i.e., that the connection between explanans and explananda is entailment or some modal connection i.e., 'necessity' etc.). This underlying assumption rests on a further assumption, that mathematical or logical representations, and the relations holding between them, are one thing; relations holding among things/events/processes *in the world* are quite another. That is, there is a fundamental difference between a mathematical theory in which I may (successfully/adequately) represent the world as having a certain structure (logical, etc.), and a theory's actually capturing *the causal structure of the world* (this latter item would constitute the "real" relations among things/events/properties that an ontic, as opposed to epistemic or modal, explanation is supposed to provide to us). Not all mathematical representations of the world (theories), so the thought goes, express the *causal* (or "real") structure of it, and if they lack such a connection to the world, they're not good scientific explanations after all. Supposing (claims Salmon) that one can provide a convincing philosophical *analysis* of what (metaphysically speaking) those relations are (a convincing analysis of the "causal structure of the world", for example), then we may interpret our scientific theories (their representational structures, their predictions, etc.) *in light of this philosophical theory* (Salmon 1984). Note the conceptual order: the philosophical account of causal structure comes *first* (and we may add the constraint that it must account for, or at least not conflict with, what we already know to be true of the world, which is a function of both experience and well-confirmed scientific knowledge); scientific *theories* are then interpreted with this (now background) metaphysics of causation in place. We may now say that scientific theories are revealing to us the causal structure of the world; we now know exactly what it is that our theories are describing because we now know something—a bit of deep metaphysics—about what the world is really like (it's by and large a *causal* world, with causal regularities and patterns to it, all of which science is trying to capture, for various purposes).

What differentiates the ontic structural realist, in particular, from the causal-mechanical view (at least with respect to Salmon's conception of it) is that whereas the former analyses causation in terms of *production* and *interaction*—that causes "bring about" their effects, and that interactions are responsible for changes in the "order and structure" of nature, the structural realist thinks that a description of the structure *is all there is to explanation because that's all there is to reality itself*. There needn't be production or interaction, in other words, for there to be *determination* or the "fixing" of certain facts relative to others. In other words, the ontic structural realist is committed to a view of determination (which you may call "causal" but which often seems inappropriate) which is not necessarily tied to temporal order or the "generation" of change from an interaction at a particular region of spacetime. This is the crucial difference, finally. Since OSR rejects the view that systems may always decompose into part-whole relationships (the mereological view), and on account of OSR's view that what an 'individual' is is fixed by context and not by its "inner constitution" or "intrinsic properties", change does not depend on matter-in-motion, and a fundamental description of the universe is not one of the temporal evolution of systems (the dynamical "Hamiltonian" view often adopted in physics).

Explanation, as I have argued elsewhere[58] in the context of QM, needn't be so limited.

The retreat in the foundations of physics community from entity-based or more generally causal explanation is often accompanied by the push for what has been called "structural explanation" (Hughes 1989), grounded in (following, somewhat, Janssen 2008) the *kinematical perspective*. There is an entire tradition that embraces a deeply kinematic spirit of interpreting quantum theory, going back to Heisenberg's famous "Umdeutung" of 1925 (and possibly earlier, with Minkowski's famous 1908 geometrical formulation of Einstein's 1905 theory of special relativity). We find more recent incarnations of this spirit in the "algebraic" and "logical" interpretations of QM, notably in the schools of interpretation advocated variously by Gudder, Bub (1974), and Stairs (1984). Indeed, this is the spirit which motivates many instances of the "modal" interpretation of QM, especially in the work of Bub (1997)[59].

I suggest that a metaphysics of structure may underwrite such a tendency to go "kinematic", or propositional rather than "physical", and that in so doing we thereby move away from "ontic" explanation in the causal mechanical sense, to an "ontic" explanation in a thoroughly structural realist sense. And this, furthermore, can be understood as a species of "structural explanation", now grounded in a metaphysics of structure. Thus, we might gain "understanding" in the sense in which Salmon had in mind, but without the need to tie such an understanding to entities

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[58] For example is Stuckey, Silberstein and Cifone (2008b)—see appendices.
[59] Which is really a propositional-kinematic reconstruction of Bohm's theory, now taken to be an instance of a "modal" theory

and/or *causal mechanisms*. This reinterpretation of the “ontic” form of explanation also allows those who embrace a kinematic perspective in QM, for example, and who also favor a structural model of explanation to be realist. Given that realism is no longer taken to be one of an entity sort, we might unproblematically invoke “measurement” in our interpretation of quantum theory, so long as it is clear that this concept serves merely a functional role in the context of a structural explanation. In particular, we may introduce the concept of measurement if it reflects the more fundamental (structural) idea that quantum theory introduces, to borrow from Bub (1974), abstract structural constraints that events are held to satisfy. Bub clearly intends this when he understood (in 2004) quantum mechanics to be “about information”. He characterized the theory of quantum mechanics in terms of information-theoretic constraints, and in so doing, measurement enters into the interpretation. Even though the concept of ‘measurement’ might play a fundamental role in the context of information theory itself, Bub is certainly allowed to give such a notion a structural gloss in the following algorithmic and operational way:

> Take ‘measurement’ to be simply the *correlation* between one physical system and its possible physical states (called “the measured”), and another physical system and its possible states (called “the measurement apparatus”).
>
> Let the physical states of each respective physical system constitute an event space (perhaps, the space of possible “yes/no” measurement questions that can be “asked”) – that is, formally represent the two physical systems in propositional terms, if you like. Next, show that this system is isomorphic to an “information system” in Shannon’s sense.
>
> Apply three *information theoretic constraints* to this system (no bit commitment; no superluminal signaling and no cloning). It can now be shown that the resulting theory is QM.

Notice, ‘measurement’ simply is a short-hand term for a correlation between one physical system and another. The principles can be understood as *purely kinematical* restrictions on the state-space adumbrated above, which entails characteristically *quantum* correlations. The constraints are structural or, in particular, are kinematic. Two problems now remain: the measurement problem (obviously) and how to explain distant EPR-Bell correlations.

I look at Bub’s basic proposal (in his 2004, 2005 papers) in a bit more detail in the next chapter, before moving on to Huw Price’s attempt to win back Einstein Local Realism. We can understand Price’s proposal to be one that essentially tries to reinstate a clear causal explanation for quantum mechanical phenomena, that may possibly satisfy a causal-mechanist like Wesley Salmon. I argue that Price’s proposal fails, and that some more radical picture of explanation is called for—that QM is telling us that causal interactions in space and time are simply not enough for an adequate explanation of the physical world[60].

[60] The full argument has been articulated in Silberstein, Cifone and Stuckey (2008b), where we also propose that structural views such as our “Relational Blockworld” interpretation of QM fare better than mechanical, backwardly-causal views such as BCQM. I refer the reader to our (2008b) and (2008a) papers in the Addendum, where we fully elaborate on Relational Blockworld (which adopts the perspective of relational, ontic structural realism as a methodological program in accordance with the point of view I developed in the previous chapter).

Chapter 3: Information Theory as a Non-causal-mechanical Account of Nature: Making Room for Realism in Quantum Information Theory.

1. Introduction. The recent work on the foundations of quantum mechanics in the light of information theory suggests a change in physics that many in the foundations of physics community are attempting to articulate. This change, I want to suggest, represents a challenge – but one that has been only vaguely articulated. The work of Bub (2004) and Clifton, Bub and Halvorson[61] (2003) suggests one way of formulating the challenge. Theirs, I believe, is a direct challenge to the received view in physics, the causal-mechanical view.

The information theoretic interpretation of quantum mechanics, I hope to show, constitutes a species of what I have been calling "ontic" structuralism, the view that the most fundamental explanatory tools open to the scientist need not be causal mechanisms in, e.g., Salmon's sense, nor does the explanation need to rely on the postulation of fundamental constituents in the sense, e.g., of the kinetic theory of gases (what Einstein called a "constructive" theory). And insofar as our attitude to this (quantum) information theory is that it is "true" (in the conjectural, tentative sense we spoke about in the first chapter), we say that it provides the true *structure* of nature, as far as the theory allows (in this case, the structure has to do with an information theoretic construal of *signaling in space and time*—a feature of nature to which special relativity, though with different mathematical laws, corresponds). I have used the term "non-causal mechanical" to illustrate that even if one does not

[61] Hereafter, CBH.

adopt the perspective of ontic structuralism explicated in this dissertation, my point still stands: that there is no *a priori* reason why only causal-mechanical (with a metaphysics of entities in causal interaction) explanations are valid, and that the information theoretic interpretation may indeed be considered a species of *realism*—just not a realism of entities. It is not a huge leap to see that the form of this non-entity realism is just what I have called "ontic structuralism", by another name.

Clifton et. al. (2003) have suggested a way to characterize quantum theory in terms of three information-theoretic principles. Bub has furthermore claimed, in his "Why The Quantum?", that this can resolve long-standing conceptual worries about quantum mechanics; in particular, he argues that the measurement problem becomes a tractable and less mysterious problem *vis a vis* information theory. There are two potential worries that Bub's project faces: (1) the lack of agreement on the meaning of 'information' – and especially, the meaning of "information in the physical sense", as Bub wants to think of it. Unless it is given some clear meaning, the assertion that "information is physical" is obscure. (2) Other information theorists have made claims that quantum information theory (QIT) provides clarity and solution to the foundations of quantum mechanics. However, most simply rehearse either a kind of antirealism or instrumentalism, in that they invoke an epistemic view of the quantum mechanical state[62]. Does Bub's position threaten to reduce to a similar rehearsal of either antirealism or instrumentalism with respect to physics in general, and quantum mechanics in particular? I will argue that Bub need not be committed to antirealism or instrumentalism. In fact, I want to suggest a way in which Bub's position could be

[62] *See* e.g.: Fuchs 2001b, 2002b; Fuchs and Peres 2000 and Duvenhage 2002.

construed realistically. Where this position falls short, as we'll see, is in not providing an account of what the world *is* like, if physics is not about the stuff we have taken for granted: particles, fields, waves, and so on. He has simply left an ontological void in the wake of the information-theoretic characterization of quantum mechanics.

I have, consequently, two primary objectives, which motivate another, secondary (although by no means unimportant), objective:

Objective 1: "Fuchs' dilemma", as Hagar (2003) puts it, is: "either he is a realist, but has not solved the measurement problem (which is fatal for his project) or he is not". Bub claims that the measurement problem is solved, if you do not construe it as a "definiteness" problem. Bub also skirts the issue of realism. Many quantum information theorists seem to take either an instrumentalist or antirealist line regarding QM. Does Bub's position amount to more of the same? If Bub, though, *is* an antirealist or instrumentalist, then his position becomes uninteresting – antirealism/instrumentalist does *all* of the interpretive work. The extent to which Fuchs' position collapses, for example, is the sense in which he takes an epistemic view of the quantum state, which Hagar argues is an inconsistent view (following Hemmo[63]). Does Bub's position face the same specter of realism? I will argue that it does not, allowing that quantum mechanics is not about the behavior of classical waves, particles, and so on. This is not to imply antirealism or instrumentalism though! It is at least a denial of the causal-mechanical view, presupposed in virtually all disputes over classical and quantum mechanics. *But the denial of the causal-mechanical view is consistent with the truth of realism.* This distinction, between the

[63] *See* fn. 28, p. 14 in Hagar 2003 (manuscript) for citations.

issue of realism on the one hand, and the issue of the causal-mechanical view on the other, is paramount: they are really logically distinct issues[64].

Objective 2: Looking to the current philosophical literature on quantum information, there is much confusion as to how to understand ‘information’. I will try to clear up this confusion. It is a confusion over whether information should be thought of as an entity or as a property; many want to argue that it is a property. However, interestingly, Bub wants to say it is an entity – indeed “a new kind of entity”. I will clearly distinguish the entity vs. property issue, and will distinguish several senses of information *qua* property that help resolve the issue of whether classical information is a “new kind” of information as Josza (1998) wants to suggest.

Objective 3: I would like to formulate unambiguously the challenge to physics suggested by Bub and CBH, by extending Bub’s discussion and by invoking the distinction developed as my first objective which shows that realism is only of orthogonal concern for Bub. Bub’s proposal – if taken to be the denial of the causal-mechanical view of physics – sheds light on the old Einstein-Bohr debate, which in turn suggests a way of articulating exactly what the puzzle is regarding the change to quantum mechanics. Bub’s work, and the view suggested in Clifton, Bub and Halvorson (2003), represents a switch from the long-standing causal-mechanical view of physics to something else that is decidedly non-causal-mechanical. This, I suggest, was the fundamental problem from the very inception of the debate over classical and

[64] Not everyone would argue that realism and the causal-mechanical view are logically distinct. For example, van Fraassen (1989) argues that “epistemic realism” should be understood as involving a commitment to the causal-mechanical view (p. 97-9). Thus, since the common cause principle is violated by quantum mechanics, and that this principle is necessary for a causal-mechanical account of the word, QM *prima facie* implies a kind of anti-realism. I simply deny this: it is consistent to be a realist about QM *and* think that QM is true of a non-causal-mechanical world. *See* my section 3 below.

quantum mechanics: can physics be causal-mechanical after quantum mechanics? Bohr's fundamental motivation, it seems, was to be anti-mechanistic; realism is a somewhat orthogonal issue for him. So, to the extent that the dispute is over Einstein's realism vs. Bohr's antirealism, the dispute is confused. The understanding of Bohr as anti-mechanical differs from the traditional interpretation ascribed to him as advocating some form of antirealism (the denial of the thesis that science is about the existence of mind-independent entities)[65]. We shall see if this is plausible.

After briefly discussing the CBH result, and after outlining (again, briefly) Bub's project of fleshing out the philosophical implications of the CBH characterization theorem, I will satisfy my objectives in turn: section 3 will be devoted to the first, section 4 to the second and last objectives.

2. The Project: "CBH Theorem" And The Explanation of Quantum Mechanics.

Recently, as recent as the early 1980s, quantum mechanics gained a fresh perspective from information theory. The fundamental motivation for this view is a powerful foundational methodology: the search for deeper and "higher" level principles at work in Nature that quantum mechanics obeys. As Nielsen (2001) points out in a talk given at the University of Queensland in Australia: physicists, in possession of the powerful predictive engine of quantum mechanics, have used it without really

[65] At least some thinkers have undertaken a comprehensive task of re-understanding Bohr as not so much of an antirealist, but as advocating a very subtle and sophisticated notion of measurement interaction that is necessarily contextual (for example, Howard – both in private and in some of his lectures – has been suggesting this). It is consistent to think both that measurement results and the resulting descriptions of objects/events in the world are contextual *and* that physics is "really about" the mind-independent existence of things. Simply because physical descriptions are necessarily contextually constrained does not imply antirealism (understood as the denial of the thesis that physics is "really about" the mind-independent reality of entities).

understanding it; the rules are used without knowing "why the quantum"[66] – i.e., without knowing the principles of the Universe in virtue of which it is quantum mechanical. He writes:

We've known the basic rules of quantum mechanics for quite some time, yet we have a quite limited understanding of those rules and the higher-level principles they imply. (2)

In the spirit of the quote by Nielsen above, CBH propose to "raise" three seemingly innocuous principles to the status of *laws* of nature (CBH 2003, p. 1562). They see this move as similar to Einstein's when he proposed to postulate both the principle of relativity and the light principle that allowed the derivation of a more fundamental physics: Special Relativity (hereafter, SR)[67]. Presumably, these three laws would, in a certain sense, *explain* quantum mechanics, just as the two postulates of SR in a sense, explain it (i.e., explain the extended life of elementary particles showering into earth-bound labs whose life otherwise, in stationary frames, is rather brief, etc.).

The sense of explanation, roughly, would be one of explanation by derivation: quantum mechanics is *explained by* the information theoretic laws of nature because quantum mechanics can be *derived from* these laws (as the CBH paper purports to demonstrate). This would, putatively, satisfy Nielsen's "quest":

> [Quantum information theory] is … the quest to obtain a set of higher level principles and heuristics about quantum mechanics analogous to those which a master chess player uses when playing chess. (2001, 2)

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[66] Originally, Wheeler's question.
[67] *See* CBH p. 4 and Bub pp. 2-3 for elaboration.

The hope with authors like Clifton, Bub and Halvorson, is that quantum mechanics – seen through the theoretical guise of information theory and dressed in C*-algebras – will reveal those deeper, higher-level principles at work in Nature. And the hope *also* is that when we are in possession of such higher-level principles, which dictate the (information-theoretic) structure of Nature, we will be able to resolve certain long-standing foundational/philosophical problems plaguing quantum mechanics, such as the measurement problem[68].

3. Implications of the CBH Theorem: Quantum Mechanics Is Not About Quantum Objects. Some of the philosophical weight of the CBH work is elaborated in a recent piece by Jeffrey Bub (2004) entitled, appropriately enough, "Why The Quantum?". His paper is devoted to arguing for three theses. I quote them verbatim:

- *Thesis 1: A quantum theory is best understood as a theory about the possibilities and impossibilities of information transfer, as opposed to a theory about the mechanics of nonclassical waves or particles.*

- *Thesis 2: Given the information-theoretic constraints, any mechanical theory of quantum phenomena that includes an account of the measuring instruments that reveal these phenomena must be empirically equivalent to a quantum theory.*

- *[Thesis 3:] Assuming the information-theoretic constraints are in fact satisfied in our world, no mechanical theory of quantum phenomena that*

[68] *See* Bub (2004) for example—esp. pp. 261 ff.

> *includes an account of measurement interactions can be acceptable, and the appropriate aim of physics at the fundamental level then becomes the representation and manipulation of information* (p. 1)

Thesis 1 is an implication Bub wants to draw from the CBH characterization theorem itself. The idea is this. By taking a restricted subclass of noncommutative C*-algebras – the abstract algebraic structure of quantum mechanical observables and states – at face-value, so to speak, one does not try to interpret their Hilbert space representation (guaranteed to exist) as a phase-space representation with respect to which the states of QM are interpreted as representing a complete catalogue of properties and the observables are interpreted as representing properties like position and momentum. One is left to treat quantum mechanics, then, as really about the "possibilities and impossibilities of information transfer, as opposed to a theory about the mechanics of nonclassical waves or particles" (*ibid.,* 242). The suggestion is that the source of the conceptual problems with quantum mechanics stems from attempting to see its Hilbert space representation as a kind of quantum analogue of a phase-space representation of classical mechanics, in which the behavior of non-classical waves or particles is described. Representing all physical theories in terms of C*-algebras allows this point to be made very precisely. Part of the importance of CBH's work is to make this point clear.

The conjunction of Thesis 2 and 3 is the heart of Bub's paper. Thesis 2 is the claim that, supposing a certain set of information-theoretic constraints (principles)[69]

[69] They are: no superluminal information transfer, no broadcasting (related to the "no cloning" result in quantum information) and no bit commitment.

are true of a class of C*-algebras is equivalent to quantum mechanics is true (i.e., these information theoretic constraints *logically imply* that the C*-algebra is quantum mechanical), then since there exist entangled states: (a) the (C*-algebraic) theory cannot unambiguously be extended to the measuring instruments and (b) any *causal mechanical* theory will have excess empirical content over a quantum theory.

Thesis 3 is the most radical. As I see it, the most plausible interpretation of this thesis is that Bub is suggesting that we think of physics (and quantum theory in particular) not causal-mechanically, but non-causal-mechanically[70]. If QM is not fundamentally about the behavior of (non-classical) particles, waves, etc., (thesis 1) and if we take seriously the claim that information is an "entity" which is "physical", as Bub proposes, *then the most plausible interpretation of this is that there are no "causal mechanisms" with which to "construct" an ontology* – i.e., physics is to be construed non-causal-mechanically[71]. If quantum mechanics is a truly fundamental theory, fundamental to physics, then if QM cannot support a causal-mechanical view of the world, physics (ultimately) cannot.

3.1 No Mechanical Theories From Information-theoretically Constrained C-algebras.* The most general way to think of physics is this: initially, we make

[70] I am not fully articulating the exact kind of non-causal-mechanical view being suggested— it is really irrelevant here (though it should be considered a species of ontic structuralism as articulated in this dissertation). Bub is simply implying a critique of the causal-mechanical view and hasn't yet provided a positive ontological account in non-causal-mechanical terms.

[71] Originally, Bub tried arguing that there did not *exist* a mechanical theory underlying QM, which is obviously too strong (private communication). He tried launching this argument by making clear the distinction between principle and constructive theories, arguing that QM is best seen as an example of the former. I now think that the real work such a distinction could do is provide a way of eschewing talk of causal mechanisms. If a theory is a class of principles, then *prima facie* it is *neutral* regarding any *underwriting* ontology. This provides more freedom to think of other ontologies that are non-causal-mechanical which may underwrite the principles. This is what I think Bub is ultimately suggesting.

measurements with certain instruments that yield some result or other with a certain frequency. We take the "observables" to represent changes in a physical system; the measuring instruments record such changes. We take "states" to represent probability distributions over measurement outcomes. The most abstract language for this kind of physics is a C*-algebra, where we consider very general kinds of observables operating on very general kinds of states. The C*-algebra, in the sense sketched above, is treated instrumentally at the outset. Now, we might want to replace this theory of states and observables with a theory of evolving dynamical quantities. That is, we might want a phase-space representation of the C*-algebraic structure. Why? Because we might like to think that physical systems "really" must be characterized by those properties we think of as being "real", "fundamental", or "constitutive of the system" etc. We may think that properties like position and momentum are such quantities that are most important about a physical system, in terms of which other quantities can be defined. So, we want to know how such a system evolves as a function of these – we want a phase-space representation. Now, according to two basic representation theorems, if the algebra is commutative, then we are guaranteed the existence of not only a Hilbert space representation, but also a phase space representation of that algebra[72]. This is good news for classical mechanics, since its algebra is commutative. Thus, we're guaranteed a phase-space representation. Furthermore, we're guaranteed to be able to describe the *instruments themselves* as being "composed" of physical systems with these dynamical properties – independent of the states of the systems being measured. We have a complete description of the physical world.

[72] *See* Bub (2004a) for technical details, esp. pp. 10ff.

Can this be done for quantum mechanics? Bub wants to argue that it cannot be done, if one restricts their consideration to empirically well motivated interpretations or rival theories to QM. Now, from the CBH theorem itself, "a theory satisfies the information theoretic constraints if and only if it is empirically equivalent to a quantum theory" (Bub 2004, 257). So the trick becomes to either show that some rival interpretation is actually empirically *inequivalent* to a quantum theory, or else show that the extra structure in some empirically *equivalent* quantum theory lacks evidential support. There are, in general, two cases that must be dealt with: (1) so-called modal or "no collapse" hidden-variables theories (of which Bohmian mechanics is the prototypical example[73]), or (2) collapse theories (like the GRW theory).

The extra *mechanical* structures underlying the statistics in Bohm's theory are particle trajectories in configuration space with accompanying "guiding waves" (quantum mechanical wave functions). If the initial distribution of the particles, from which we might derive their trajectories (along with a wave function), is the so-called "Born distribution", then the resulting quantum statistics is equivalent to any quantum theory, and so won't violate any of the information theoretic constraints, via the CBH theorem (Bub 2004, pp. 257-8). But,

If the information-theoretic constraints apply at the phenomenal level then, according to Bohmian mechanics, the universe must be in the equilibrium state, and in that case there can be no evidence for Bohmian mechanics that goes beyond the empirical

[73] All modal interpretation are equivalent in the sense that they all specify the dynamics of some definite observable. For Bohm, it is position (*see* Bub 2004a, 14). As well, Bell argues that the many worlds interpretation is equivalent to Bohmian mechanics modulo particle trajectories (*Ibid.*).

content of a quantum theory (i.e., the statistics of quantum superpositions and entangled states). Since it follows from the CBH theorem that a similar analysis will apply to any 'no collapse' hidden variable theory or modal interpretation, there can, in principle, be no empirical grounds for choosing among these theories, or between any one of these and quantum theory (*Ibid*., 258).

With a collapse account, like GRW, Bub points out that it violates one of the information-theoretic principles: the impossibility of unconditionally secure bit commitment:

> "Since the GRW noise [read: hidden degrees of freedom] is uncontrollable in principle, there will be entangled states associated with this larger Hilbert space that cannot be prepared, and so cannot be exploited for steering [Schrödinger's way of talking about nonlocal changes to quantum measurement statistics]… This suggests that unconditionally secure bit commitment would, in principle, be possible [by accessing these hidden degrees of freedom]. (*ibid*., 256)

To count against the truth of Bub's claim, any counterexample must at least satisfy the conditions of the theorem (both the information-theoretic constraints and the kinematical essence of QM). GRW does not, and hence does not count against Bub.

Where does this leave us? If we cannot specify any empirically supported underlying mechanical structure (that is, some phase-space representation underlying the statistical structure of the observable algebra) or if any attempt at recovering "definiteness" results in violating one or more information theoretic constraint or if we end up with an empirically *inequivalent* theory, *and* we want to take quantum theory seriously (as a truly fundamental theory), then we should believe that "*our measurement instruments ultimately remain black boxes*" which implies that we treat quantum mechanics as *about* the statistical outputs of *information* sources. The fundamental entity is not particles, waves and so on – it is information; that is all. The problem with QM is really an historical contingency: we developed classical mechanics first out of the 17th century, where it was very popular to see the world causal-mechanically[74]. Consequently, physics sought to find a representation of these causal mechanisms, and so any mathematical representation of nature ultimately was judged over its ability to find expression as a complete catalogue of properties of these causal-mechanical particles – a *phase* space representation.

It might be thought that Bub's basic position is nothing other than a kind of antirealism or instrumentalism regarding QM – nothing other than a statistical interpretation with the aim at being metaphysically agnostic. Indeed, one might be tempted to this view because many other quantum information theorists seem to be arguing for an epistemic view of the quantum mechanical state and some form of instrumentalist or antirealism. If so, then Bub's position is uninteresting, since instrumentalism or antirealism would be doing all of the interpretive work. If our theories are merely "instrumental" then there is no bother over ontological worries; if one denies that our theories are about a mind-independent reality, then there can be no worries over that reality as far as our theories go.

But to take such a view of the CBH project and Bub's subsequent foundational work with it, would be to *miss* the essential point: quantum mechanics is about the behavior of information, not classical particles, waves, etc. This does not

[74] *See* Ernan McMullin's (1989) discussion of the causal-mechanical view in relation (historically) to "distant action".

entail either instrumentalism or antirealism (*or* realism for that matter). Realism is actually consistent with CBH's project and Bub's position, as I will now argue.

4. Realism Is Not The Real Issue: Blocking Instrumentalism and Antirealism From CBH. It is unfair to believe that CBH and Bub's elaboration of its foundational significance might be just instrumentalism (or antirealism) in disguise. Quantum mechanics need not imply a dispute over realism and antirealism[75]. It can simply imply a dispute over whether we can maintain a causal-mechanical view of physics or not; that is, whether we can hold fast to the somewhat misnamed "criteria of reality" Einstein adamantly propounded: locality and separability[76]. These two criteria are *at least* necessary conditions on a causal-mechanical view, if not the very definition of it[77]. The well-confirmed violation of Bell's Inequalities establish that separability and locality cannot be true of a quantum world[78]. Thus, QM since it violates these inequalities, implies the falsity of the causal-mechanical view. This suggests that we view the change from classical to quantum mechanic as the shift from the causal-mechanical view to a non-causal-mechanical view.

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[75] I wish to understand realism and antirealism following Devitt (2002): realism is, on the "existence dimension" of it, a claim that "most of the essential unobservables of well-established current scientific theories exist mind-independently". Anti-realism is the denial of this claim. This way of construing realism is *neutral* to any *underwriting* ontology: existence could be predicated to causal-mechanisms *or* non-causal-mechanisms (Platonic Forms, Aristotelian essences, and the like).

[76] *See* Bub 2005, p. 543ff.

[77] Van Fraassen (1989) argues for a similar point (*see esp.* pp. 99ff). Although van Fraassen takes a denial of the a causal mechanical view to be a denial of "epistemic" realism, I find that realism and the causal-mechanical view are distinct, as I argued in the Introduction of this paper, and as I argue in the present section.

[78] Technically, the violation of Bell's Inequalities imply the falsity of the common cause principle, which is logically equivalent to the conjunction of the separability and locality principles (probabilistically formulated).

We can then see that there are two orthogonal problems with respect to QM: realism vs. antirealism/instrumentalism on the one hand, and the causal-mechanical view vs. a non-causal-mechanical view on the other. The issue of realism can only make sense with respect to some background ontological scheme, such as the causal-mechanical view, where it is clear what kinds of things we can be realists about or what our theories are about (i.e., what sort of mind-independent reality there is). For example, it is one thing to be a realist about a causal-mechanical world (of particles, waves, fields, etc.); it is quite another to be a realist about a non-causal-mechanical world (say, a world of Aristotelian essences – abstract, formal properties not reducible to Democritean atoms – or, of Platonic Forms). Indeed, I might be a realist about information – but not think that it reduces to the classical ontology of the causal-mechanical world-view (as Bub claims of information)! If some interpretation of QM does not buy into the background ontological scheme of the causal-mechanical world-view, then it is unfair to charge it with antirealism or even instrumentalist unless such a charge is made relative to that background.

I believe that it is the *fairest interpretation* of the CBH result, and Bub's subsequent elaboration of this result, to see it non-causal-mechanically. This reading is fair in that it does *not* see their work as being doomed to anti-realism or instrumentalism right from the start. It allows them room to be realists, but realists *not* about the furniture of a classical world. It allows them to be realists about a nonclassical world of information, which mustn't reduce to the classical ontology (although one *may* try to argue that it does). I am not arguing that they must be realists; my argument is that there is logical space for them to be. In this way, then, it would be entirely unfair to charge their project as being antirealist or instrumentalist from the get-go.

This way of interpreting the project distinguishes it from other information-theoretic projects which are overtly instrumentalist[79] or only awkwardly realist[80]. Thus, CBH and Bub's own foundational project based on it, are not necessarily antirealist or instrumentalist. Denying particles, waves and the like is not denying realism; it is just changing ontology. The burden then becomes articulating that ontology precisely.

5. The Real Worry: Information as Property or Entity? In the current literature on the subject, there seems to be much confusion over the question of how to understand 'information'. Some think that *quantum* information "does not exist", in that it is nothing more than Shannon Information (Duwell 2003); others think that it is a new "kind" of information (Josza 1998) distinct from *classical* (and here Duwell and Josza are in disagreement[81]). Landauer[82] claims that "[i]nformation is not a disembodied abstract entity; it is always tied to a physical representation" and hence he wants to draw the implication that information is physical; likewise for Steane[83]. Timpson (2000) argues against this view; he thinks that the claim 'information is physical' is

[79] *See* Duvenhage (2003) for an approach to quantum information which is instrumentalist.
[80] Fuchs claims to have a realist project; however as Hagar argues quite convincingly, if one adopts an epistemic view of the quantum mechanical state, then it is almost impossible to be realist about QM.
[81] *See* Duwell (2003), pp. 479-80.
[82] Quoted in Timpson (2000).
[83] *Op. cit.*

false. So, for Timpson, information is *not* physical. Information is not to be thought of as an entity at all[84]. Bub flatly denies this.

This confusion is made worse since most authors want to invoke information in either an antirealistic or instrumentalist context; few have attempted to see information realistically[85]. Fuchs (2002b) takes the quantum mechanical state to "[represent] a collection of subjective degrees of belief …" (p. 5) and to be "solely an expression of subjective information – the information one has about a quantum system" (p. 7). Fuchs' project an "epistemic view", "can be rendered consistent," Hagar writes, "only at the price of denying even the weakest form of realism" alluded to by Fuchs (Hagar 2003, p. 763). Duvenhage sees the quantum state in a way similar to Fuchs: it is "a mathematical object which for each possible outcome of each measurement that can be performed on the system, provides the observer with the probability of obtaining that outcome when performing that measurement" (2002, 4) – implying a kind of instrumentalist attitude toward QM and an epistemic view of the quantum mechanical state[86]. Duvenhage regards information as being "about a physical system" that "is a set of probabilities [an observer] assigns to the outcomes of all measurements which he can perform on the system" (p.2). The mathematical object that expresses this for him, then, is the quantum mechanical state.

How can we make sense of all of this confusion? Specifically, can Bub defend the claim that information is a new kind of entity? I think Bub can, if we take him to

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[84] Timpson 2000, p. 16

[85] The work of the Horodeckis seem to want to go realist, or at least physical, with information. *See esp.* their (2003) "Quantum Information Isomorphism: Beyond The Dilemma of Scylla of Ontology and Charybdis of Instrumentalism" for an interesting suggestion in this regard.

[86] On the potential inconsistency of realism and the epistemic view, see Hagar (2003).

be effectively denying the causal-mechanical view. If we take Bub non-causal-mechanically, then many of the worries generated will go away.

In general, there are two possible ways to see information: either as a property of something (like a physical communications system in Shannon's sense) or as an entity in its own right. For each sense, there are further issues that arise.

5.1 Information as Property: Functional vs. Essential. If one wants to understand information as a property, then there are two possible interpretations, either as (i) a functional property or (ii) as an essential property. For example, 'being a computer' or 'being a Turning machine' is a functional property: to be one of these things is to satisfy certain abstractly specified conditions ("roles"), which can be "realized" with many kinds of entities (computers can be made out of wood, water and pipes or silicon). Functional properties do not pick out natural kinds in the world. In contrast, 'being a piece of gold' is not a functional property: to be gold is to have a certain fixed sub-atomic configuration. It is, therefore, an "essential property" in this sense. An essential property is a property that if a thing did not posses it, *it would not be that thing* – it would cease to exist a the thing it is.

If information is nothing but a functional property, then 'having information' means 'instantiating certain abstract conditions'; for example, we can take those conditions as none other than the Shannon communication system itself[87]. The only sense in which information is physical is the sense in which it gets "realized" in physical systems like a Shannon communication system. But then it seems that the

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[87] *See* Shannon 1948, p. 2.

only difference between quantum information and classical is a difference in the kind of physical stuff in which the information is realized: quantum information is that which is realized in quantum mechanical stuff, and classical in classical stuff.

However, there seems to be some disagreement in the literature as to whether this analysis is right. Is quantum information *nothing but* the quantum analogue to classical information (*a la* Shannon), or is quantum information a *new* kind of information? Duwell (2003) argues that "quantum information does not exist" in the sense that it is nothing more than classical Shannon information multiply realized over different physical entities (some quantum, some classical)[88]. Thus, Duwell is claiming that (Shannon) information is a functional property, realized with various entities (characterized with their own essential properties). As such, Shannon information is "sufficient" for quantum information.

Jozsa (1998) argues that quantum information is a *new kind* of information in the sense that there are certain properties of quantum information (namely, entanglement) which distinguish it from classical information. Duwell wants to take issue with Josza: quantum information does not exist. However, there seems to be confusion here.

But saying that quantum information is a "new kind" need not immediately commit one to the insufficiency of Shannon Information for quantum information, if Shannon information is functionally construed. Of the class of things defined

[88] But, if quantum mechanics is truly a *fundamental* theory, then in which sense is there anything "really" classical? Either (i) QM is complete, and classicality is an appearance, or else (ii) QM is not complete, and some things can be really classical. If (i), then there is really no classical information; if (ii) then there can be.

functionally as ‘information’, we may further specify two sub-classes, quantum and classical. Josza has something to say about this: quantum information is “new” in the sense that to be quantum information is not only to satisfy the functional property ‘information’, but also to possess an essential property that makes something quantum: entanglement. The possibility of ‘being entangled’ is an essential property for something’s being ‘quantum’.

Thus, it is consistent to say that Shannon information is sufficient for quantum information *and* to say that quantum information is *different* from classical (because of the possession of a further essential property) – unless you identify Shannon information with classical information. But if you think that Shannon information is basically a functional property, then there is not motivation for such an identification.

5.2 Information as Entity? Consider the following central philosophical remark towards the end of “Why The Quantum”:

> So a consequence of rejecting Bohm-type hidden-variable theories or other ‘no-collapse’ theories is that we recognize information as a new sort of physical entity, not reducible to the motion of particles or fields. An entangled state should be thought of as a nonclassical communication channel that we have discovered to exist in our quantum universe, i.e., as a new sort of nonclassical ‘wire’. We can use these communication channels to do things that would be impossible otherwise, e.g., to teleport states …. A quantum theory is then about the properties of these communication channels, and about the representation and manipulation of states as sources of information in the physical sense” (2004, p. 262).

The picture of the world Bub endorses is one in which information counts as physical entity, but the ‘how’, though, isn’t explained. Bub does not specify what an entity is such that information counts as one; furthermore, it’s not clear how this entity relates to other characteristically ‘physical’ entities like particles or waves—or if Bub is rejecting the whole idea that the world is fundamentally composed of particles and fields. Indeed, it's not clear what Bub means by 'physical', because, as we've seen, one standard response to his view is that all it amounts to is a particularly egregious form of hypostasis—treating an abstract concept as a physical object or 'entity', if you will. The least that Bub seems to be saying is that not all physical entities are sums of, or at any rate dependent upon, the standard panoply of ontology which includes particles and/or waves. But, it is reasonable to request of Bub's position that it outline why this isn't hypostasis. In other words: insofar as there is a prior and reasonable distinction to be made between 'abstract' vs. 'physical' (i.e., concrete, non-abstract and physical) entities, and insofar as 'information' is plausibly construed as an instance of the former (this is Timpson's, and to some extent Hagar's, contribution to the discussion), then unless some thesis is advanced to address this distinction itself, there is good reason to suspect that Bub has committed the fallacy of hypostatization.

But, let us take notice of the fact that this charge of "hypostatization" really depends upon a particular *prior* way of dividing physical from non-physical—of making the distinction between concrete vs. abstract, that is. In fact, when we think about what is meant by 'physical', the usual response is: *composed of non-mental stuff*, stuff like chemicals and compounds, which ultimately are composed of elementary particles/fields and their intrinsic properties (or we way become a little more sophisticated and say that 'physical' and even 'physical entities' are nothing more than bundles of properties). Everything else, you may say, in some sense depends on that. One way of articulating this dependency is to invoke a relation like “supervenience”: *all* facts “supervene” on the physical facts, where the content of the concept ‘physical’ is supplied by *fundamental physics* (particles/fields, waves, and their intrinsic properties, which are things like charge, spin, mass, etc.). The view seems to be that unless entity X depends upon some set of physical facts Y, then X is abstract. It is characteristic of abstract entities that they are autonomous and independent of minds, societies and beliefs and physical stuff. Mathematics can be thought of as the study of abstracta: numbers, the concept of infinity, and sets are abstract in the sense that they *themselves* do not depend on there being any physical facts all and certainly do not depend on minds, beliefs and societies (so goes the view).

Bub, though, can easily reply to the charge that he’s committed the fallacy of hypostatization by treating information as a physical entity. He can simply say “so what? Even if information is an ‘abstract’ entity according to your distinction, the claim on the table is that when the world is construed in quantum information theoretic terms, so long as it’s clear, operationally speaking, what an ‘information theoretic system’ amounts to, and in particular what a ‘communications system’ is or could possibly be ‘made of’, then what I have done is provided the *principles that govern such abstracta*! As long as information theoretic systems are construed functionally—just like the concept of a hammer or a computer may be understood functionally—then just about *any* collection of things, under the right conditions and with the right structure, may count as an information theoretic system, and so be under the purview of the principles of quantum information theory as has been characterized (CBH 2003). This is just like saying that when I’ve got the right system of wood, pulleys and so on in place such that I may compute a function, I've got a computer and therefore certain *mathematical* truths will apply (i.e., Church-Turing thesis, principles of computation, combinatorial mathematics, etc.). If anything, I am saying something that has been noted for generations now: mechanical systems are describable by vector calculus; information theoretical systems are describable by information theory—and with the right configuration, even a mechanical system may be considered an information theoretical one, though perhaps the latter just doesn't reduce to the former. Now, if anything is wrong here, it's with *your* narrow construal of 'physical' or 'concrete' in terms of particles/fields or waves. All that I am telling you is that 'information' does not *reduce* to, or is not a compositional sum of, those entities, and that the laws of quantum mechanics are 'about' the possibilities of information transfer, communication, etc. Now, just like a the idea of a 'computer' must be realized by 'physical' objects, it is still true that the laws of computation are such as to be true of just about any sort of computer. Indeed, this is the hallmark of an objective science—by definition. Indeed, what I am really saying is that 'entity' is much more general concept that the classical picture allows for. Why should my characterization of the world have to fit the mold of the classical picture of the world, where all that we're supposed to be describing is the behavior of particles/fields or waves? *That* would be a way of begging the question against my point of view. Abstracta may differ from concreta, but surely both it seems a stretch to say that because an entity is abstract, then there can be no scientific laws about it, or that the universe may, in limited was, be conceived of as an instance of an abstract concept (like that of a computer), as functional the concept turns out to be, in the end". And indeed, making this argument—that Bub's position amounts to a non-causal mechanical view and that this implies—has been the purport of this chapter.

As I see it, Bub is really re-asserting Quine's dictum, albeit one freed of the idea that particles/fields or waves are the only acceptable 'physical entities': get your ontology from fundamental physics—even if that requires generating a more abstract and less "stuffy" sort of ontology than that characteristic of the classical view we find, for example, in Newton. Indeed, certain abstracta, like the abstract, functional concept of 'computer', find many instances, and these instances obey suitably abstract laws (that of logic and computation, let us say). To say that every computer is realized by some conglomeration of physical stuff (non-abstracta) is not to say that the laws are untrue and fail to refer. Maybe we just don't think that such kind of theories—those that refer to abstracta—don't count as fundamental physical theories. Surely, though, Bub's opponent owes him an explanation as to why his information theoretic characterization of quantum theory *cannot count as a fundamental theory of the universe*. In other words, Bub's opponent owes him a story as to what counts as a "fundamental theory"—an argument that has not be made. And *this* question—what counts as a fundamental theory—does not seem to admit of a perfectly general answer. Indeed, as I'll explain at the end of this dissertation, this question is open, as open as any theory is open to empirical investigation. So, unless Bub's opponent just stamps their feet and insists that all interpretations of theory or fundamental theories all require an ontology of particles/fields or waves by which one may construct (or build up to) the physical world (lego-style), then Bub's opponent is simply begging the question.

But, the opponent might persist, what I am really requiring is that unless your ontology is such as to allow for a description of *all* fundamental physical processes (at least those that are the purview of quantum theory—and we must include here the *process of measurement itself*) in terms of the behavior of this fundamental ontology plus the dynamical laws that coordinate the behavior of that fundamental ontology, then this ontology, and this interpretation in general, is *completely inadequate*. So, our opponent claims that we cannot build a picture of the basic processes of nature out of the quantum information theoretic account, nor can we, in particular, resolve the measurement problem.

How could the interpretation do this, if there is no appeal to entities like particles/field or waves—entities which are such as to allow for spatiotemporal locatedness, and are such as to *move*. Those sorts of entities are, we may say, concrete in the sense that they have (in principle) *definite* and *determinate* spatiotemporal features. Abstracta—functional 'objects' like computers or 'informational systems'—do not themselves have spatiotemporal locations, but their concrete exemplars most certainly *do*. Information *qua* entity (let us say even *qua* abstract entity) does not have a "location", spatiotemporally speaking, in the same way that particles or waves have spatiotemporal location. That which is a concrete physical realization of (quantum) information will always have a spatiotemporal location—and so the quantum mechanical problems of recovering definiteness and determinateness, that is of recovering an apparently "classical" world from the quantum one—will *only* arise whenever we attempt to tell a story of the quantum world in terms of an ontology of particles/fields or waves. And only *here* does a measurement problem arise.

5.3 An analysis of 'measurement'. Recently, Bub has addressed precisely the issue discussed above in more detail, and has developed a more nuanced approach to the question being raised here, which is *just what is being required of a quantum theory so that a solution to the measurement problem may be given?* In particular, what is a measurement, anyway? Bub claims (personal communication):

> The new empirical discovery underlying quantum mechanics that clashes with the causal-mechanical view of classical physics (as extended by Einstein's relativity theories) is that *there exist information sources that cannot be cloned*. Putting it differently: *there is no universal information-cloning machine*… [i]f you could clone the information source, then you would have [in a twin-slit experiment, for example] a classical distribution at the back of the slits and not the interference distribution. So, the essential step in the break with classical physics is noncommutativity or the Uncertainty Principle. […] If you have information sources that cannot be cloned, i.e., if there is no universal information-cloning machine, then there can be no such thing as measurement in the sense that we usually think about measurement is a causal-mechanical theory.

So, according to this view, the "no universal cloning machine" theorem, which can in information-theoretic terms be proven of quantum theory, implies that "there can be no such thing as measurement" in the usual sense, which is that there is (ideally) a perfect *correlation* between the states of the measurement apparatus and the states of the system being measured—i.e., the measurement apparatus effectively *clones* or copies the physical states of the measured system. Insofar as there exist no universal cloning machines, then *no* such measurements *exist* according to Bub's information theoretic interpretation of quantum theory.

> To put it simply [he writes]: 'no universal information-cloning machine' means 'no measurements' (in the usual sense). So we have to take our measuring instruments—ultimately—simply as classical information sources, i.e., a 'black boxes' no susceptible to a dynamical

> analysis. That is, in any measurement situation, there must always be some ultimate measuring instrument that is not analyzed any further dynamically and is just functioning as a classical source of information, i.e., it produces some classical probability distribution of events. …[Y]ou can always push a dynamical analysis of the instrument further (there's no absolute stopping point…), but that just pushes things one step back to some other 'ultimate measuring instrument'. This is a conclusion of the analysis prompted by the discovery that some information sources cannot be cloned (and empirical discovery elevated to a principle underlying quantum mechanics as a new theory of information…); measuring instruments much (ultimately) function as 'black boxes' or classical information sources.

This is a strong thesis. It implies that any causal-mechanical story of measurement *requires* that there be cloning, which is disallowed. Thus, there is a dilemma: either there is no measurement problem, or universal cloning is possible. Bub's position entails, therefore, that *there is no measurement problem*. Furthermore, Bub claims that this interpretation—which is essentially arguing for a particular *analysis of the meaning of 'measurement'*—is analogous to what Einstein provided with his special theory of relativity, which is an analysis of the meaning of 'simultaneity'. Bub explains:

> So, quantum mechanics is not a theory of waves and particles of a new sort but a theory of information and how it relates to classical information. From this point of view, there is no measurement problem: the problem arises if you persist in thinking about quantum mechanics in the old way. The analysis … resolves a foundational problem in a similar sense to the way the puzzle about light is resolved by Einstein's analysis of simultaneity. For Lorentz, the fact that the velocity of light is constant was something to be explained, e.g., by 'constructive' assumptions about electrodynamical interactions in the ether that are responsible for the contraction of moving rods. For Einstein, there is nothing to be explained here (in the sense of providing a mechanism for some puzzling behavior): the puzzle is resolved by the analysis of simultaneity (i.e., there is no puzzle). Similarly, GRW theorists postulate a constructive 'collapse' mechanism to explain how you get a classical probability distribution is a measurement interaction. But there is nothing to be explained here from the point of view of the information-theoretic interpretation: the

> analysis linking the behavior of measuring instruments to the impossibility of a universal cloning machine resolves the puzzle (i.e., there is no puzzle).

So, Bub now proposes as one fundamental principle the principle that there is no universal cloning machine; this is a principle that "governs" (if you will) the "behavior" of information transfer.

It is not entirely clear why Bub's proposal is not as "physical" as Einstein's. Both begin with, in effect, an analysis of measurement: for Bub, the analysis concerns the basic structure of measurement which involves a correlation between the states of the measured system and the (internal) states of the measurement apparatus; for Einstein, it also involved measurement, but one having to do with a more fundamental consideration of simultaneity—what it means to say that two events 'happen at the same time' (which notion is involved in *every* measurement of length, which is a fundamental feature of any physical system). Bub calls such kinds of theory "constitutive", involving, as they do, a consideration of what constitutes a *proper measurement*, or better, what is excluded from the concept of measurement: in QM (according to Bub), it is *cloning* that is prohibited (one you formulate quantum theory information theoretically); in relativity, it is *absolute simultaneity* that is prohibited (that is, there is no universal standard of spatiotemporal measurement that stands outside of every physical process, including that of measurement[89]). Both

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[89] This is exactly what the conjunction of the two principles of special relativity lead to: all determinations of space and time are fixed by the speed of *electromagnetic processes*, is a constant and independent of the motion of its source. In effect, this means that *only one* length is absolute: $x = ct$, which is the amount of 'space', if you will, described by a beam of light. But this 'absolute length' is essentially dependent upon a particular process in nature, and so does not leave space and time independent of every natural process, which in turn implies an absolute notion of simultaneity (this is Newton). Einstein simply realized that this notion of simultaneity was at the heart of Lorentz's attempt to account for the laws of electromagnetism, in conjunction with the null result of the famous Michelson-Morley experiment. Dropping the idea that spatial and temporal facts are in principle

theories, in their turn, imply something about the proper *form* of theories in its domain: in relativity, the proper form is determined by *Lorentz invariance*; in Bub's formulation of QM, the proper form of theories is that is manifest a non-commutative state-space geometry—not merely apparently, but *really*. That is, according to Bub, any reconstruction of quantum theory that *adds* another (hidden) variable to the theory will be analogous to introducing an ether hypothesis whose purpose is to smuggle in an absolute notion of simultaneity. In other words, Bub's position is that any "solution to the measurement problem" will be such as to re-introduce a notion of measurement that is inappropriate for quantum theory (in essence, the old notion of measurement was such that, in the language of information theory, cloning was possible in principle).

The point with all of this is that Einstein's theory is as "physical" as Bub's proposed re-interpretation of the quantum theory in information theoretic terms. Insofar as the notions of velocity and space and time have clear operational meaning in relativistic mechanics, Einstein's theory is physically meaningful and can find concrete physical instances; *mutatis mutandis* for Bub's information theoretic reinterpretation: as long as we can conceptualize any physical system as an informational system with 'physical' components, then Bub's is a 'physical' theory, at least as much as Einstein's. Bub's view implies, however, is that there is no absolute deconstruction of the process of measurement which is not itself going to obey the non-commutativity of the quantum theory. That is, there is no absolute

independent of every natural process (including measurement) led Einstein to the special theory: we have evidence, in effect, that at least one velocity is *independent from its source* (electromagnetic velocities), and thus we may hang our temporal and spatial determinations around this fact, rather than beginning with the assumption of absolute space and time and trying to fit all facts into *that* framework.

measurement—no “universal cloning machine”—and so every measurement apparatus must remain, essentially, a ‘black box’, an incompletely analyzed correlation-generating information source.

6. A species of ontic structuralism. Bub’s latest view amounts to a species of ontic structuralism. Another way of understanding the basic thesis of the ontic structuralist is that there is no absolute, non-structural decomposition of the physical world—all entities (individuals) are metaphysically derivative from structure, and there is (in principle) no end to this structural analysis. In other words, there is no “complete” account of the physical world that bottoms out in terms of non-structural “fundamental constituents”. The causal-mechanical view is a metaphysical view that precisely demands what the structuralist regards as illegitimate, for it regards *everything* as determined by the interactions of fundamental constituent parts which have their own, independent, self-contained nature.

In the case of Bub’s information theoretic interpretation of quantum theory, what is disallowed is a construction of *all* fundamental processes in terms of fundamental constituents; some elements of the picture must remain unanalyzed. If we *did* allow such a view, then according to Bub’s interpretation, we will run afoul of the principle of “no universal cloning machine” in the case where we apply this causal-mechanical doctrine to the processes of measurement itself. The question is, then, what sort of a world are we left with if, according to QIT, the fundamental “entity” is information, and there can be no absolute decomposition of the world along causal-mechanical lines? The most plausible interpretation here is that Bub's QIT describes the true structure of the world in terms of informational systems, which may be "composed" of just about anything, given the right configuration and under the right circumstances. In other words, inasmuch as we may physically construct systems that are the functional equivalents of quantum computational structures (effectively building the quantum analogue of classical communications systems that, e.g., Shannon first described), we may build a kind of quantum computer which instantiates the right sort of computational structures that will, in turn, obey Bub's principles—and the claim is that *every* quantum mechanical system may be conceptualized and treated in this manner. We may even go a bit further here, and invoke the possibility that there may be no limit on how "large" systems may be that display quantum mechanical effects (something that, e.g., Sir Anthony Leggett has written on). Indeed, there may be radical length-scale invariance here: if the conjecture of Leggett's is right[90], then just about any collection of objects at *any* level of scale may manifest quantum mechanical behavior, so long as one can suspend the effects of what has been called "environmental decoherence" (ED for short). The sense in which we arrive at an ontic structuralist view of the physical world is seen when you realize that what Bub is really saying is that given the complete generality

[90] Relatively macroscopic objects such as benzene molecules have been shown to exhibit quantum interference effects, for example. So, these systems counts as quantum mechanical systems if any do—irrespective of size. Only quantum coherence counts. The conjecture of Leggett's is: why, in principle, should we expect quantum mechanical effects to drop off on the order of the length-scale of viruses, bacteria, lipids, chemical compounds, etc.? Supposing that ED can be appropriately and effectively controlled, thus inducing a coherent quantum state, there seems to be *no in principle* length-scale limit to what systems will exhibit quantum mechanical effects—possibly whole planets or solar systems. It follows that, for example, a *quantum information system* may be constructed with the appropriately ED-controlled, macroscopic elements. So, just as a computer can be constructed out of wood, water and pulleys (as Searle famously pointed out in the context of philosophy of mind) *for which the laws of computation apply*, likewise for a "quantum computer" (an instance of an informational system) made out of ED-controlled bits of physical stuff.

of the laws of quantum information theory, what is being described is not the motion of non-classical particles or waves, but the modal structure of informational systems—what can and cannot be done (the "possibilities and impossibilities of information transfer") in the world, quite *irrespective* of "what it's made of" (this, finally, is what we're to be 'realist' about, should we choose to invoke that terminology). Bub's QIT is insensitive to "what the world is made of"; it only cares to provide the structure of what there is, come whatever details you like to fill in for the material stuff. And this, finally, is what relativity provides: a description of what can and cannot be done in the world, a description of the form the laws of "what there is" must obey.

Chapter 4: Quantum Mechanics from the "Archimedean" Perspective: Between Dynamical *Explanation* and Non-dynamical *Description*.

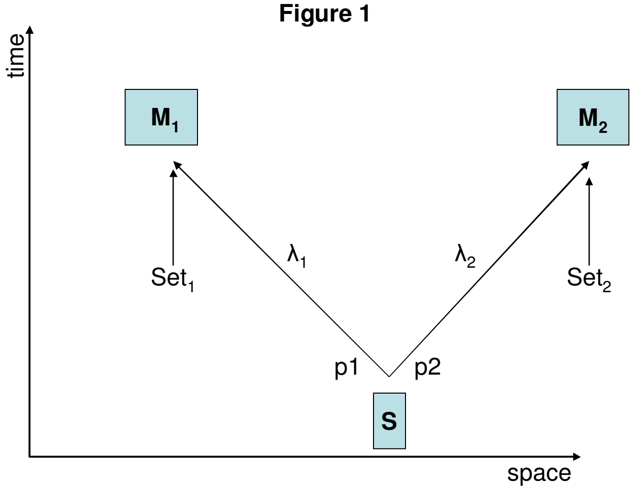
1. Introduction. The purpose of this essay is to explicate Huw Price's "Backwards Causation Quantum Mechanics" (1996, 2001) with the goal of revealing the deeper philosophical implications regarding explanation and the status of (dynamical) laws in a universe where this interpretation is true. The metaphysical and epistemic perspective Price adopts for this view is what he calls the "Archimedean" perspective – the perspective of a timeless observer. We will pursue the question: can this "timeless" perspective be reconciled with Price's insistence on the explanatory role of backwards causal dynamical influences?

After bringing out the nature of explanation and the status of dynamical laws in a universe where not only is BCQM true, but where we adopt a timeless interpretation of it in such a world, we will ask a further question regarding the plausibility of invoking "backwards" causal influences to explain phenomena in this universe. This analysis will suggest several philosophical problems or potential objections to Price's view. The most serious potential objection is that these backwards causal influences threaten an explanatory regress (perhaps to the big-bang), hence rendering explanation empty (even allowing that "Einstein local realism" is consistent with BCQM). Finally, we will argue for an interpretation of Price's view where "causation" is a compromise between the dynamical and non-dynamical perspectives Price vacillates between. Thus causal talk, albeit "perspectival", *reconciles* both the dynamical and non-dynamical points of view adopted by Price. Here, we will explore what the right attitude ought to be with respect to dynamical laws from the Archimedean point of view. In particular, we will explore the possibility of moving beyond a dependence on dynamical laws for "explanation" – where the Archimedean does not just describe, but can discover non-dynamical laws (principles) that truly explain *why* events are the way they are[91].

2. EPR: As simple as 'B causes A'? Bell took for granted – as physicists tend to – that the future cannot determine the past in the sense that the initial state of some physical system is statistically independent of the events in its future light-cone. Price, considering this to be an unjustified assumption in the Bell proof, constructs a model of epr phenomena without assuming that the past does not depend in some important sense on the future, at least when it comes to microphysical systems (of, say, electrons, photons, etc.). Consider the basic epr configuration, in schematic spacetime-diagram form [figure 1].

[91] Arguably, this is what we have been doing all along with the "principle" methodological strategy which Einstein – one's of its champions – ironically derided as a method of "desperation". In the ideal limit of physics, though, perhaps principle is all that we will be left with.

Figure 1



Schematic spacetime diagram of basic EPR experiment
(Price 2001)

It might be that the quantum state prepared at the source is actually dependent on its future measurement interactions. Bell (1993) seemed to think that this would amount to a possible world which was

> even more mind-boggling than one in which causal chains go faster than light. Apparently separate parts of the world would be deeply and conspiratorially entangled, and our apparent free will would be entangled with them. (p. 154)

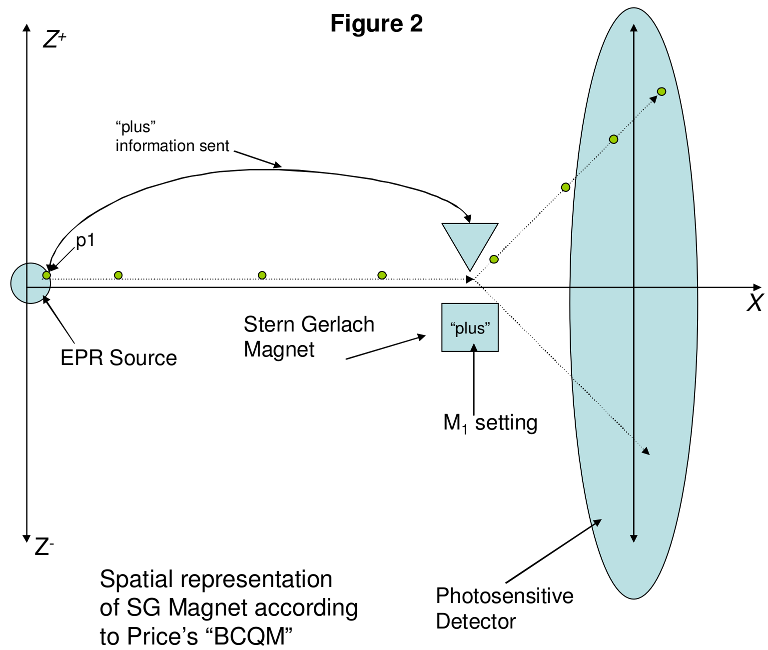
This possibility can be ruled out by stipulating the "independence assumption (Price 2001, 199):

> *Independence Assumption* (IA): The values of the hidden variables λ_1,λ_2 are independent of the measurement settings Set_1, Set_2

This means that we can imagine the future measurement settings varying such that the probability distribution $\rho(\lambda)$ does not change. If, contrary to IA, we do allow this probability distribution to depend on the measurement settings, then a very simple explanation of the Stern-Gerlach distribution pattern in an EPR-Bohm set-up [figure

2] is possible: the particles “know” which way the apparatus is going to be oriented, and with this information they move accordingly.

Figure 2



If we want to embed this story in spacetime, it looks like we have to posit *backwards causation* as the physical mechanism responsible for the failure of IA, as Maudlin (1994) notes:

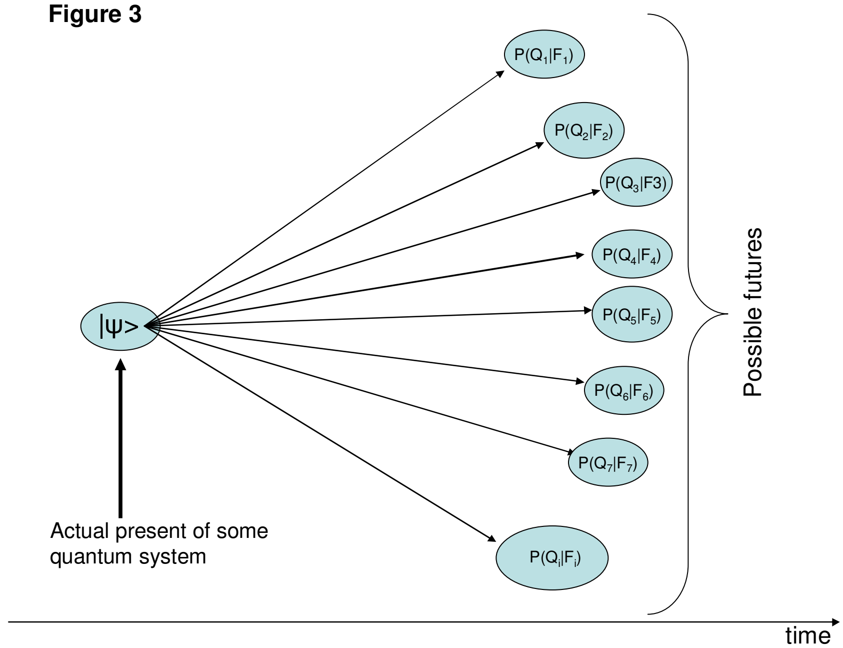
> Since the settings of the measurement devices can be performed in the absolute future of the creation of the electrons, and since the settings can be determined independently of the process which creates the electrons (e.g., the setting could be determined by a computer program running a complex algorithm), any theory which denies [the independence assumption] must posit *backwards causation* …. (285)

The denial of IA opens up the possibility of something like a "common-cause" explanation of EPR-Bohm, albeit in reverse: information about SG settings is sent along the backwards light-cone of each sg apparatus M_1,M_2 where this common information *coincides* at the source of the particle pair so that each particle can "possess" the information about its future. It is not in virtue of only a *past* common causal intersection that explains the future correlations: it is the past common causal intersection (the singlet state prepared at the source) *plus* the common information about the particles' *future* measurement interaction that explains EPR. We can call this model of EPR, formulated around the explicit denial of IA, "backwards causation" quantum mechanics or BCQM, following Callender (1998, 153).

According to BCQM the determination, and hence explanation, of the behavior of epr particles is made on the basis of their future interactions, as well as their past. With this kind of symmetric determination, in one fell swoop not only is the peculiar lack of a continuous spread of particle *positions* explained quite simply (Bell 1987, 142), but also explained is the *outcome correlation* between M_1 and M_2 (separated by a spacelike interval): information about the future lands backwards in time at the source of particles. Since quantum theory itself does not provide this necessary information when describing the initial EPR singlet-state, the theory is an *incomplete* theory. When completed, the new quantum theory will have a completely "local" and "realistic" interpretation in Einstein's sense, although now somewhat restricted.. This is a crucial point.

Consider figure 3. The quantum state $|\psi>$ is "highly potential": it encodes information about what would happen to the state under certain experimental conditions. We can represent this as a set of conditional probabilities for the outcomes of possible yes/no measurements (Price 2001, 204): { … $P(Q_i|F_i)$ … } is the probability that the i-th proposition Q obtains given that the i-th measurement F was performed.

Figure 3



As in figure 3, the quantum state from this point of view encodes information about its possible future: it provides information about the likelihood of a particular outcome when subjected to certain experimental conditions. Modulo any interpretive moves at this point, we take each likelihood to be a (non-overlapping) possible world, where only one world is selected at the time of measurement – the actual future.

Suppose, however, that the universe is something like a "block" universe, in which the past, present and future are equally real. Suppose that there is what Price would call an "Archimedean" observer who can "survey the future as well as the past" (*ibid.*). From this observer's point of view, there is only one *actual* future. For this observer, the picture of quantum theory sketched above is massively redundant: *most* of the information in $|\psi>$ is information about futures which never come to be – $|\psi>$ is "noisy".

From this perspective, formulating a quantum theory in Archimedean terms would "cut out the noise" in standard quantum theory. Supplementing the theory with a hidden variable, as Price proposes, which provides information about the actual future would severely limit the standard theory. An "*A*-complete" (for "Archimedean") theory wouldn't be as "potential" as the standard theory: $|\psi+\lambda>$ will *not* reproduce all possible futures encoded in $|\psi>$ alone. As Price himself notes:

> … a hv model of this kind trades off some potentiality in return for a gain in *A*-Completeness. The values of the hidden variables … would not be predictive, in the fully counterfactual way that ψ is. To be precise, they lose predictivity with respect to the class of possible futures which they themselves exclude" (2001, 205).

The upshot of this loss of "predictivity" is supposed to be what almost every natural philosopher worrying about quantum theory was convinced is *not* a viable possibility: beating Bell with a *local* model of quantum correlations, in short the return of Einstein's "local realism". But what is perhaps an even more laudable achievement, BCQM corrects a long-standing, though not-oft appreciated, problem in the conceptual foundations of physics: the asymmetry of explanatory dependence (that the future of physical systems depends on the past and not the other way around[92]) is not reconcilable with the time-symmetry of fundamental dynamical laws, including

[92] The principle of "μ-Innocence" is an instance of asymmetric dependence in that this principle states that interacting particles exhibit correlations only after, and not before, they have interacted.

Schrödinger's. This asymmetric dependence lacks justification (be it observational or conceptual), when considering that the fundamental physical laws governing the micro-physical world are quite indifferent to "time's arrow" and that obviously *macroscopic* "arrows", like that of thermodynamic processes, are certainly not evidence upon which to infer a *microscopic* asymmetry. Perhaps because of the unpalatable "conspiracy", as Bell put it, that such a symmetrically dependent world would require, it is taken for granted that the future is *determined by* the past in a way in which the past is *not*. Bell's Theorem consequently inherits what for Price is a long-standing unjustified assumption about which way the arrow of determination points.

But name-calling is never an adequate response to a conceptual possibility, no matter how hard to grasp or counter-intuitive it might be. There is no "conspiracy" for Price[93]. By taking an "Archimedean" view of physics, which embraces something like the "blockworld" view of spacetime (the reality of all spacetime events), Price has really assumed that *whatever* the universe is going to be like, it is already there, "at once" and nothing "new" comes into being. All interactions, changes of state, choices made, outcomes realized, experiments performed, exist *timelessly*. *Whatever* patterns there ever were, are or will be, are "there". That is, from the point of view of an Archimedean observer – perhaps something akin to Laplace's or Newton's omniscient God[94] – all of the past, present and future are within view. Bound up in the fabric of this frozen spacetime are what observers from a particular perspective

[93] I am taking a somewhat heterodox position here; many natural philosophers tend to adopt the "conspiracy" interpretation of those theories which drop the λ-independence assumption. *See* Lewis (2005) for a clear analysis.
[94] *See* for example Newton's *De Gravitatione*.

call “EPR correlations” (predicted by a certain physical theory). There are other patterns, to be sure. But the patterns consist in nothing more than a comparison of three observational facts (recognized by observers within the block): facts about the preparation of a physical system, facts about the measurement devices into which these systems will go for experimentation, and the outcomes of the experiment itself. A problem arises when one takes a physical theory of how the world is supposed to work (i.e., quantum theory), makes predictions for this experimental set-up *and then reasons about what the physical system could possess at the time of preparation to give rise to the correlation in their subsequent outcomes.* Price asks how beings, from a perspective within the fabric of the blockworld, can determine the outcomes *from the Archimedean perspective*. There is, however, no “conspiracy”. It is simply that the explanatory task is a good bit different: supposing that the future is real before the particles emerge, and that the particles “have” this information, can they exhibit the correlations after interacting with the measurement device? The answer of course is yes – quite easily.

But let us consider how the explanation goes for Price’s Archimedean observer, and ask whether one can do *better* from this timeless perspective.

3. Dynamical Laws and Explanation from the ‘Archemedian’ perspective. Dynamical laws are “pushy” to borrow Carl Hoefer’s term:

> They *make things happen in certain ways*, and by having this power, their existence lets us *explain* why things happen in certain ways. Laws, we might say, are implicitly thought of as the *cause* of everything that happens (2003).

But their “pushiness” derives from the fact that they pick out, from a larger class of possibilities, either a single possibility (for strictly deterministic laws) or a reduced class of possibilities. This is the *empirical content* of a law: it tells us how the physical world definitely, or at least probably, is at a later time. However, dynamical laws aren’t so pushy in a blockworld.

In a blockworld, we imagine that from an Archimedean perspective[95], all events are “real”. Whatever the universe is going to be like, it timelessly “is”. (You might even imagine that it has “unfurled” in some sense, although the active voice is somewhat odd when it is supposed to be describing a timeless reality). So, whatever is going to happen in the universe “does” and we are left with but one possible world – the actual one. In this sense, blockworld implies the “fixity of facts”, what we can call “logical determinism”.

Immediately, in such a world, dynamical laws are not so pushy. Rather, they are better seen as a generalization of facts that *are already fixed* – a summary of what the actual blockworld is like. Recall, furthermore, that for Price one looses a measure of “predictivity” – in the sense that merely *one* possible future is fixed from the initial state of a physical system (see figure 3). But the initial state of a system, for Price and the Archimedean, is not determined from the present to the future; rather, is determined from the *future to the past*. Thus, a “counterfactual” account of laws in a universe like this (an Archimedean or block-universe) cannot obtain because, given the failure of predictivity in Price’s sense, physical systems are precisely *not*

[95] Recall that Price dedicates several pages of his 1996 monograph to the blockworld view of spacetime, where he endorses it explicitly (*see* pp. 12ff). Such a view re-emerges in Price’s later work when he asks us to imagine an Archimedean observer who can survey the past and the future when thinking about QM (2001, 204).

compatible with counterfactual statements about their present state-of-affairs[96]. Even if we index counterfactuals to statements about the whole universe, and try to defend a counterfactual account of laws accordingly, it is hard to reconcile Price Archimedean-ism with counterfactuals. A more plausible interpretation of laws for Price is the regularity-theorist's account (laws are merely regularities of the phenomena). According to this view, dynamical laws are cooked-up to match the block of already real events for our Archimedean observer. On this view, the dynamical laws are determined by the actual block of fixed events, but the block is not cooked-up (or entailed by) the laws. Dynamical laws don't push! They characterize the block of events (is if by a spacetime geometry one simply means a characteristic metrical structure between the events, then these laws-qua-regularities thereby characterize the geometry as well).

Furthermore, supposing that only one actual world is ever the case (which follows immediately from logical determinism, come whatever dynamical laws one might dream up to fit the blockworld), probability and chance are purely epistemic notions. The sense in which things could be otherwise should be interpreted epistemically, if logical determinism is true. By adopting an Archimedean point of view, the future is what it is, and likewise the past and present. There is no (non-

[96] Unless, of course, one indexes counterfactuals to statements about *the entire universe*. But in this case, these classes of counterfactuals are seemingly not empirical matters – not matters of fact. The truth of counterfactuals in these classes will depend on the nature of the initial and final conditions that gave rise to this *particular* universe. But *that* will be decided by our best theories *discoverable in that universe*. Unless there is a fact of the matter about what the initial and final boundary conditions are, and how to evolve those conditions to get the actual world, and unless there is a fact of the matter about what *other* initial and final conditions *could have obtained,* it is not clear that a counterfactual statement indexed to the *entire* state of the universe is *factual*. On Price's view, it does not seem to make sense to speak about counterfactuals indexed to the entire universe given his Archimedean view. So, it is implausible to defend a counterfactual account of laws, but more plausible to be a regularity-theorist about laws.

epistemic) "chance" for the world *to really be otherwise.* The world is "chancy" simply because no Archimedean observer is physically possible; if an Archimedean observer is physically possible – that is, if something like Newton's omniscient God were possible – then it would simply perceive, all at once, what was going to be true whenever and wherever. However, given that Price embraces Einstein local realism, and since he presumably would embrace the relativity of simultaneity (otherwise there would be little physical motivation for the blockworld view), it is hard to reconcile Newton's omniscient God or the analogous "Archimedean observer" with relativistic spacetime structure. For Price, Newton's God could not plausibly exist in a relativistic spacetime.

If what is really explanatorily important in a dynamical law, plus the relevant boundary conditions, is how selects, *from a set of possible outcomes*, the actual one corresponding to the actual world, then dynamical laws are not importantly explanatory. A dynamical law does not "select" any possible world. Recall Price's loss of predictivity for quantum mechanical systems: the present is compatible with just *one* outcome (the *actual* one that obtains *at the measurement event*) of the set of outcomes consistent with the initial quantum state. Remember that in an Archimedean universe (the blockworld) it is the block of events that determines the dynamical laws in the sense that the laws are generalizations over the "already real" events in spacetime. The events are ontologically *prior* to the laws: the laws just summarize facts about the block. In this sense, dynamics do not explain, they simply repeat back to us a generalization over the actual facts about the block. Dynamics, hence, are not the "reason" why things happen to be the way they are – things just are.

Plausibly, then, Price would adopt the *negation* of the thesis defended by Brown (2005), who argues at length that the right dynamical laws of the fundamental constitutive ontology of the world (presumably, "matter" of some kind) *determines* the geometry (i.e., the block), and the geometry *merely codifies* the behavior of that moving stuff (whose movement is governed by the dynamical laws). Therefore, dynamical laws "push" for Brown, whereas they are merely impotent regularities for the Archimedean observer – "frozen patterns" to use somewhat suggestive language. The Archimedean is therefore free to take a merely *epistemic* interpretation of dynamical laws – they are ways to *discover facts* about the frozen block – without having to (a) defend an ontological view of them or (b) without having to accord them a fundamentally explanatory role (as Brown would, for example) in science (though, relative to a non-Archimedean observer *within* the block of frozen events, they might serve the purpose of explanation *qua successful prediction* for practical purposes: from predicting where a spaceship will land in spacetime, to where and when a click in a photon-counter will appear under certain conditions).

All of this is reasonable from the Archimedean perspective, from the (admittedly physically impossible, though conceivable) point of view of God perceiving the entire blockworld. Given what we have now learned regarding the ontological, epistemic and explanatory *status* of dynamical laws in a blockworld (in particular, their inability to provide *deep* explanations for events in spacetime), how are we to interpret Price's BCQM?

4. Critique of BCQM: epr, Explanation and Archimedean physics. The philosophical worries about EPR are generated by a prediction about how measurement outcomes would be correlated in separate regions of spacetime, a prediction made on the basis of the details of quantum theory. By applying the theory to the case of measuring the "spin" of a particle, which operationally turns out to be the behavior of a given particle (often of zero total electric charge) under the influence of an inhomogeneous magnetic field, and by considering a certain kind of prepared state and its subsequent behavior when subjected to various field strengths, one compiles a record of outcomes from which a peculiar correlation between the spin states is noted. The important point is that according to the theory, by writing down an appropriate wave-function for this system of two particles, and by solving the Schrödinger equation, one obtains that while the results of measurement on either particle are equally probable, they will on average exhibit anticorrelation in their measured spin states (Bohm 1951, 617-618). In this case the dynamics (albeit statistically, with the orthodox, text-book theory or deterministically as with Bohm's theory) fixes what one will see in the lab. After performing many runs of the experiment under identical or nearly identical conditions, if the measurement results adequately agree with the theoretical predictions, we are satisfied with the dynamical law and ascribe it an important explanatory status: the dynamical laws "push" the world around to exhibit particular states. The dynamics are the reason why the world is the way it turns out to be. Part of the explanation of EPR inevitably will turn on the dynamics[97] that fixes this state's evolution (in Hilbert space), and the subsequent measurements of this state (in spacetime).

[97] Either linear Schrödinger dynamics of QM or collapse dynamics.

Since from the point of view of an Archimedean observer, all facts are fixed (logical determinism is true), dynamical laws are most-plausibly interpreted generalizations over the physical facts of the blockworld and do not determine events; dynamics simply *describes* certain features of the block, relative to certain limiting conditions. Furthermore, and this is important for BCQM, since for the Archimedean observer there is no objective chance that the world might turn out to be other than what it actually is, the dynamics is not "predictive", in a broad sense (i.e., the initial state of a quantum system is compatible merely with the actual post-measurement state of the system, *and no other*). If a necessary condition for predictivity of laws is that there really be alternative ways the world could have been (i.e, that other possible states compatible with the initial state could have obtained *for that initial state*), then in a blockworld where all facts are fixed, laws are not predictive. To repeat: the laws simply return what the Archimedean observer already knows[98], which is how the "universe unfolds" (or, more properly, how it "always is").

For Price's Archimedean observer, the specific details of quantum theory are quite irrelevant. Absolutely *any* correlations imaginable can be met if, in this blockworld, the future determines the past (and the past the future, to complete the symmetry[99]). If what was empirically interesting about quantum theory is the *particular kind* of correlations predicted on the basis of its dynamical laws, then our Archimedean observer is rather uninterested to call these correlations anything more

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[98] Knowledge here is also fixed since the entirety of what there is, is fixed. Notice logical determinism in a blockworld even implicates the "epistemic-ontic" distinction often assumed in debates about physical theories and their relationship to the empirical world. But this intriguing suggestion must be placed aside for now.

[99] The "two-vector" formalism of Aharonov, Bergmann and Lebowitz or "ABL" (1964), reconstructs standard QM in a way in which full *symmetric* dependence is worked into the quantum state itself.

than those natural to his blockworld—they are completely uninteresting for him. Allowing that the particles know their future (or, more generously, that the future influences the past), then the particles are behaving just as they should be; given other details about the physical world, particles will behave accordingly. And so on. Since we are only concerned about explaining the correlations between *measurement records* of this device, given the fact that the initial particles have the information about the future settings of the measurement devices *prior* to entering the measurement devices, the *details* of the microphysics are not all that important. The rather new explanatory task, given that we know how the EPR correlations can be exhibited in a blockworld, is to find a way of physically *modeling* such influences. The *new* task seems to be simply to show that *quantum theory can accommodate* the backwards influences in a reasonable, physical way.

With BCQM we are not explaining why things happen in certain ways; rather, we are explaining how a theory can be reconstructed on the basis of how the world actually is from an Archimedean point of view. It is, therefore, not right to view Price's interpretation of quantum mechanics as an "interpretation" at all: it is simply an attempt to show how quantum theory can be modified to produce models of the temporally-reversed influences sending relevant information about the future to epr singlet states. To use Callender's locution, BCQM is an "interpretation schema" (Callender 1998, 154). More specifically, it is an interpretation schema for a type of hidden variables reconstruction of qm, where the only function of the hidden variables is to show that if the values of the variables depended on the future measurement settings, then epr correlations can be explained. Since the settings of these measuring devices can be varied by an altogether physically distinct device like a computer carrying out a complex algorithm (Bell 1993, 154), one must *postulate* backwards causation (Maudlin 1996, 285) as a physical mechanism for the dependency.

Price is making three important, though conceptually distinct, moves with BCQM:

(i) quantum theory reconstructed from the point of view of no perspective at all (the Archimedean/blockworld perspective)

(ii) dependence of the past on the future (determination proceeds future-to-past)

(iii) postulation of backwards causation

Presumably, the conjunction of (ii) and (iii) implies (i). However, one might be cautious here. If we take (ii), the dependence of the past on the future, to be simply the *reverse bias* of "μ-Innocence" (which Price desperately wants to strike from the conceptual foundations of physics), then (ii) is *unjustified* if the past-to-future direction of determination is[100]!

4.1 The Arrow of Determination. In Archimedean physics, the arrow of determination should be bi-directional: the past and the future depend on each other,

[100] Indeed, Maudlin calls the denial of the independence assumption an "ineliminable asymmetric dependency of absolutely earlier states on absolutely later events" (*ibid.*) – though he does not intend this to be a critique of the possibility *per se*. This asymmetric dependency might become suspicious in the context of "Archimedean physics" – whose purport, according to Price, is to alleviate the unjustified explanatory bias of the past-to-future direction.

symmetrically[101]. So (ii) is best modified to conform with a strict symmetry requirement for dependency (at least in the microworld). Bi-directional dependency, however, might threaten to be too problematic from an Archimedean point of view. In what does this "dependency" consist? If an Archimedean observer surveys at will the past and the future in a blockworld, then since the past is as "real" as the future, and nothing "comes into being" which isn't already in this observer's sight, the sense in which the past "depends on" the future is rather trivial: the past *must be* what it is because the future is already real! To put the point more clearly: since logical determinism is true, then the future and past are in a fixed relation precisely "because" all *counterfactual* claims are strictly speaking false. The falsity of all counterfactual claims, given the fixity of actual facts in the blockworld, *picks out the actual blockworld uniquely*. It follows as a matter of pure logic that if the past "determines" the future then the future "determines" the past. *No physics* is needed for this dependency.

Some thinkers who have grappled with the problem of the asymmetric dependency in qm have attempted to ameliorate this problem by invoking a dubious bi-directional dependency. The so-called ABL reconstruction (Aharonov, *et al.* 1964) of qm is precisely one which incorporates such bi-directional dependence into the formalism of the theory itself. For ABL, the quantum state, given some *initial* condition, is evolved *forward* in time; as well, the state that results *after* measurement is evolved *backwards* in time, now tagged with its *final* boundary condition. A state

[101] Or at the very least, if one is worried about the unjustifiable bias given to the past-future arrow of determination in physics, then a future-past arrow invoked in explaining EPR for example *would be just as unjustifiable*. Conclusion: for a given state at a given time, that state should be determined by at least some event(s) in its future lightcone *and* some event(s) in its past lightcone.

"in the middle" that is compatible with the initial and final conditions (of measurement) is constructed—the so-called pre- and post-selected state. The predictions of the single-vector formalism without this backwards-evolved information are interpreted as "error" or as "noise". This picture of QM leaves us with a classical picture not unlike Price's, where the deviations from the classical picture are simply interpreted as redundancies, due to lack of information about the future of the system undergoing dynamical evolution. For ABL, before a measurement is made we lack information about the quantum state which, upon making a measurement, is updated and we now interpret the quantum state in light of this new information. So by the lights of ABL's reconstructed theory, we are simply learning how to update our information about systems—QM is just an "error theory" of information, whereas the world itself is perfectly classical. The Archimedean view is certainly not suggested by this reconstruction of QM (although it's compatible with it). What is worse, if we want to interpret ABL from an Archimedean point of view, then not only is bi-directional dependency no obvious *physical* dependency (given what was said *supra*), we are also left with nothing more than an *epistemic* interpretation of the quantum state. The burden now is to explain what is particularly "quantum mechanical" about the world.

4.2 Backwards Causation. The postulation of backwards causation *explains* the dependency of the past on the future: information is sent backwards in time to the singlet state [see figure 2], which in turn exerts an influence on the initial state; the past therefore depends on the future. Furthermore, backwards causation (*qua* real physical influence) avoids the necessity of invoking influences between two spacetime regions exerted at spacelike separation to explain EPR, influences which potentially conflict with Relativity. From the Archimedean perspective, though, why postulate *any* causation if (a) all facts are fixed (b) dynamical laws just repeat true generalizations of the fixed events (c) chance is ultimately epistemic (d) the arrow of determination and the arrow of time are "perspectival"? If there is any causation for the Archimedean observer, it will be relegated to the domain of perspective, and more usefully seen as a convenient fiction with which one can relate experiences *within* the block to the physics of the Archimedean perspective? Indeed, causation – or perhaps more perspicuously, the *arrow* of causation – is merely perspectival: "causal asymmetry isn't really in the world at all, but the *appearance that it is* is a product of our own standpoint" to use Price's words (1996, 155). But if the arrow of causation is perspectival, then causation is too (whatever you might think it turns out to be). If causation is deeply perspectival, then even to call causation "backwards" is something of a misnomer, for there is no physical fact of the matter as to which way time's arrow points, at least for the microphysical world. Time's arrow, on which one can hang the directionality of causation, isn't "in" the blockworld, but just a matter of one's (contingent!) perspective within it. So for the Archimedean observer, causation is strictly speaking superfluous. The concept of causation does not do anything more than provide a perspectival description of the way things *seem* to be, which is in "movement" from past to future. Archimedean physics, presumably, can get by without "backwards causation" or any "causation".

The best way to understand "causation" in Price's account of quantum theory and epr correlations is that "backwards causation" is a conceptually necessary device with which to relate two seemingly incompatible perspectives: the perspectival-less Archimedean and the ineliminably perspectival. Backwards causation quantum mechanics, then, is something of a compromise between explanations of the physical world from the ultimate, mind-independent, observer-independent, and "detached-observer" point of view versus explanations that rely on facts about information gatherers and observers tied to a particular part of space and time, with particular observations and experiences within the blockworld.

The latter view is taken from the perspective of an observer "within" the blockworld, who experiences ordinary things like change, a "flow" of time, etc. From this point of view, the future is unknown, and the past is all but a historical treatise. From this point of view, the world seems like it could be many possible ways, and from this point of view one can think that dynamical laws are really "pushy" explainers. The physics from this point of view is dynamical, and "perspectival". From the Archimedean point of view, physics consists in description of the actual world, and *relative to certain perspectival constraints*, certain dynamical laws and theories built around them will be true (i.e., true for observers within the block). So, if I stipulate certain experimental configurations, divide that configuration into "preparation state" and "measurement apparatus" and resolve that into "singlet state" and "measurement settings", etc. I get a prediction about the behavior of these items. Now I ask, in a dynamical way, what "pushes" the preparation state of particles to behave the way they do in the measurement apparatus? Clearly, many options are available, but given the blockworld hypothesis and the interpretation of this situation from the Archimedean perspective, all the events of this measurement situation are equally real, and so the dynamics of the particles don't "push" anything around. So, what determines the particles to behave as they do in the magnets? In a sense, BCQM says that it's simply the very fact that the particles *will* interact with the magnet that is the "reason why" the particles exhibit correlations. But this is trivial, it is simply the repetition of the mere fact that there are such-and-such patterns in the block. One can characterize these facts in terms of "causation" but, as we have said, this adds nothing to the explanation itself, as there really is not explanation *per se* but the description of the Archimedean point of view from the dynamical, perspectival point of view.

4.3 Explanatory regress to the Big Bang? If we keep pushing BCQM for more encompassing explanations of physical facts, it threatens to reduce to even more trivial explanations. We have argued that, relative to the EPR experimental configuration itself, the causal influences are explanatorily superfluous – indeed so are the dynamical laws used to generate the predicted correlations – from the Archimedean perspective. But we have taken for granted this experimental configuration, and have not asked for a BCQM-type explanation for any of its sub-systems. Particularly, we might ask about the explanation for the singlet-state itself. What explains the entanglement at the source of the photons. According to BCQM the correlations that define a singlet/EPR-state are explained by the particular settings of the measurement apparatus out to which the particles move *in the future*. The arrow of determination goes from future to past, though from our experiential perspective it looks like things "move" from the past/present to the future. Let us grant this for the moment and ask how a singlet state is actually prepared in the lab.

Singlet-states can be prepared with a single-source of particles (say, a sufficiently heated bit of metal where electrons are exchanging energy and emitting photons in the process), though this is not necessitated by quantum theory itself[102]. The usual understanding is that at some point, two independent quantum systems, represented by their own unique wave-functions, "combine" or "interact" so that their combined spin components, for example, become correlated even though their individual spin might be random or non-random (Bohm 1951, 400-1). It follows from BCQM that the explanation for the interaction of these systems – that they interact at all, and become correlated – must derive from the fact that each system "possesses" this information already, before the process that leads to their correlation. So, the "source" state is both an explanans, and an explanandum: it itself is *explained by* an influence from the future measurement-interaction, *and* the source *explains* the fact that independent quantum systems are to be correlated. And of course, this logic must proceed all the way down along each and every quantum system's worldtube, down to the very creation of the systems themselves – presumably at the big-bang. But this would explain only the particular epr event in question. Since this particular system will presumably interact with many systems over the course of its entire history, all information relevant to its future course must end in the big-bang. In fact, not-unlike a Leibnizian monad, this system must contain within it *all* information about the entire universe, at least in principle. For, given that this system S_1 interacts with another system S_2, information about both must be equally shared everywhere along their respective worldtubes, converging on the big-bang – and so on. And if the universe

[102] *See* Hardy (1992), where he exploits "interaction-free" measurements to generate EPR states, where the particles exhibiting EPR correlations have never interacted and so share no common source.

happens to be one for which there is a “big-crunch” on the other end, then absolutely every system will possess information about every other system, since they all share a common point of convergence in the future. And, add to this the fact that the notion of “system” itself is somewhat of a loose term (especially if one interprets quantum states, with Rovelli (1996), relationally[103]), then explanation *must* in some very deep sense be relative to how one divides the universe into system-subsystem, so that this Leibnizian interconnectedness does not render the explanatory project quite literally empty.

Again, this dynamical perspective, if taken to its logical extreme, seems to collapse under its own weight: the demand for backwards causal influences necessitates that information about the *entire universe* be (at least potentially) had by each system. Moreover, as one sub-divides systems into more fundamental component systems, more and more explanatory relations will emerge. Of course, such information is presumably available to the Archimedean observer, but it seems absurd to postulate an “influence” which, *when interpreted realistically*, makes each system (at least, each micro-system of the universe) potentially omniscient in itself. Surely, Archimedean physics can do better, and can do without “causal influences”.

5. Conclusion: Moving Beyond the Dynamical Perspective. The lesson, ironically, that we have learned from the Archimedean observer is that in a blockworld, explanation is perspectival. Ultimately, explanation collapses to description from the

[103] Since Price offers us merely an “interpretation schema” we are presumably free to consider some possible ways to interpret the specific details of quantum theory itself, like its state, dynamics, etc., according to some other interpretive systems.

Archimedean point of view. From this perspective, there are no *real* influences – influences are an *appearance* within the blockworld. And to the extent that physics tries to derive law-like generalizations of the appearances, traditional physics (the perspectival, dynamical physics of the ordinary kind) is right on the money. As Arthur Fine (1989) says regarding the search for influences and the "dynamical tradition":

> The search for 'influences' or for common causes in an enterprise external to the quantum theory. It is a project that stands on the outside and asks whether we can supplement the theory in such a way as to satisfy certain *a priori* demands on explanatory adequacy. Among these demands is that stable correlations require explaining, that there must be some detailed account for how they are built up, or sustained, over time and space. In the face of this demand, the tangled correlations of the quantum theory can seem anomalous, even mysterious. But this demand represents an explanatory ideal rooted outside the quantum theory, one learned and taught in the context of a different kind of physical thinking. It is like the ideal that was passed on in the dynamical tradition from Aristotle to Newton, that motion *as such* requires explanation (p. 192).

And so in this dynamical tradition, the motion is attributed to some kind of causal influence impelling the matter forward (perhaps the dynamical law is a description of the real influence?). But again, from the blockworld perspective, motion too is merely an appearance and an explanation of it in terms of an "influence" will be to "explain" one perspectival aspect of reality with another – one appearance explains the other. In the blockworld, all physical facts are fixed – none being "responsible for" another in a dynamical, causal sense.

Fine's point should be emphasized, but restricted to the context of our present investigation. The search for influences *is* a project external to quantum theory. But the kind of project it is will be constrained by certain metaphysical hypotheses about the physical world and the nature of physics from the deepest metaphysical point of view in that world. Understood in the context of Archimedean physics, the search for influences amounts to modifying qm to suit our intuitions and experiences of the apparent forward-directed-ness of reality. BCQM represents something of a compromise between, on the one hand, explanations couched in terms of embedded experiences of the physical world, and on the other hand the demands of physics from a non-dynamical, perspective-less point of view. We have been arguing, however, that the final step in this Archimedean progression should be to break free of the need to invoke causes altogether, and re-conceptualize the experiments altogether – to explain the world from the *ultimate* Archimedean perspective.

Let us be specific on what counts as the Archimedean view[104]:

(1) Dynamical laws do not determine events (they aren't "pushy"), but are generalizations of observation of physical phenomena. Dynamical laws are merely phenomenological.

(2) Explanation at the fundamental level is description; at the less-fundamental level, explanation is pragmatic and relative to a particular context/goal

[104] Perhaps this is the proper stance regarding *truly fundamental* theories: at least ontologically and epistemically, one ought to be *neutral* regarding the exact details of the dynamics of the matter in motion (theoretical pluralism should be maintained at that level of explanation), while embracing a realism of the structure of the principles of physical theories comprehended from the Archimedean point of view. This kind of view might reconcile a "Lorentzian" pedagogy with an Einsteinean one that seeks more and more abstract *principles* of nature (and less and less dynamical details). But the thesis defended here is that Price's view is one where there is a tension between *dynamical* attempts at explanation from within the Archimedean view, versus *non-dynamical* descriptions attainable *come whatever dynamical details known to non-Archimedean observers (like us!)*.

(3) The "perspective-less" *fundamental* level of description should be consistent with the "perspectival" *less-fundamental* levels of explanation/description

(4) The descriptive apparatus used at the fundamental level should determine the set of possible perspectival less-fundamental descriptions. This means that the physics at the fundamental level should determine the physics of the perspectives, so to speak.

(5) The ontology of individual stuff (particles, fields, waves, wave-functions, etc.) and dynamical laws of that stuff do not determine "what happens". All events are equally real, timelessly exist, and don't "come into being".

If we take Archimedean physics seriously, and we think that there is something true of the world captured by quantum theory (yet we are not willing to interpret the theory as being "incomplete" in Einstein's sense, as Price does), then one would *expect* to find quantum mechanical experiments that outstrip dynamical perspectives such as BCQM. Such experiments will make plain the uneasy compromise between the dynamical, perspectival view and the non-dynamical, non-perspectival view. We would interpret these experiments as not calling out for more exotic dynamical and perspectival explanatory stories, but for a deeper Archimedean point of view which encompasses all of these dynamical stories. This perspectival-less fundamental point of view should be one for which one can provide an *explanation* of the less-fundamental perspectival stories themselves! The job of the Archimedean physicist is not only to model nature but also to tell us how nature could appear to be dynamical, and she does this, for example, by explaining how quantum theory can be so bizarre when one demands from it a dynamical model of the behavior of the phenomena it predicts. The Archimedean physicist is also a *natural philosopher*.

Chapter 5: Summary, Objections and Replies.

I'd like to conclude this dissertation with a summary of the thesis defended here and a consideration of some major objections, and their replies, to structural realism itself (we will be careful, of course, to distinguish between the epistemic *versus* the ontic versions of structural realism and adjust the focus of the objections accordingly). This summary will give us an opportunity to understand the extent to which the objections in the literature impinge on the thesis of ontological structural realism central to this dissertation. We need to keep this summary in mind as we work through potential objections.

1. Summary of Ontological Structural Realism as defended in the present dissertation. The view, and implications of it, that I've set forth in this dissertation may be summarized as follows. I shall lay out the summary piece by piece, for easy of reference.

Ontological Structural Realism (OSR) and Epistemic Structural Realism (ESR) are compatible. Rather, the two positions are mutually supporting. The thesis of the contextuality of individuals is crucial here: relative to a certain fixed background, whenever we examine the structure of an atom, we find what we can think of as 'individual objects'. But, from the point of view of a deeper analysis—that of the theory of relativity of from quantum field theory—the notion of an individual breaks down. Nonetheless, the concept is useful, *relatively* so. In other words, we *are* inquiring into "more than structure", but this must be understood as: physics postulates certain primitive individuals (like an "elementary particle"), and over time, learns of deeper structure; thus, the individual must be understood as having a relatively limited and dependent status that changes over time. So the claim that we know "only structure"—the claim that Demopoulos and Freidman, following Newman (1928), charge Russell with defending (see section 2 below)—is indeed trivial, but only if you take a *static* view of the knowledge derived from physics. Recall that part of the motivation of the structural realist was to *also account for theory change* in such a way as to capture what was/is successful about a theory, and which survives the change. It is structure, with the individuals presupposed at each temporal slice of the history of science changing such that they can be reinterpreted in light of a deeper and wider scope of scientific knowledge. Ontological structural realism and epistemic structural realism are natural companions with this view of theory-change in sight.

The claims that OSR rejects: (a) "things-in-themselves"; (b) 'natures'; (c) substances with "intrinsic" properties (d) self-subsistent individuals (that is, individuals whose 'individuality' is grounded in a metaphysical essence or essential property like "haeccity" or "primitive this-ness". All of (a)—(d) are *conceptually and metaphysically unnecessary to account for what we know about the world according to our best sciences, especially fundamental physics*. In other words, OSR is at the same time a "naturalized metaphysics" (see Ladyman *et al*. for an extended polemic on naturalizing metaphysics). Note that our naturalized metaphysics is in the spirit of Quine, who famously said that "philosophy of science is philosophy enough", but importantly different regarding the *form* that the metaphysics from science takes. It is anti-Humean, and is importantly different from the recent alternative to Humeanism defended by Tim Maudlin (2007).

OSR and reductionism, holism. We always have to be careful with the issue of reductionism, as Silberstein (2002) points out in detail, since questions of compatibility with it will turn on what one means by 'reductionism'. OSR is not compatible with *ontological reductionism*, or even *mereological reductionism*. OSR is compatible with a notion of "holism", but this will really depend on what the meaning of that term is. Since most versions of holism are centered around considerations of the system/whole-subsystem/part question in fundamental physics, and are in particular motivated by the issue of non-separability and entanglement of quantum theory, OSR will entail holism with respect to quantum theory (that the properties of wholes are not in general exhausted by the intrinsic properties of their parts), but there is an important conceptual difference. Holism is usually devised to handle specific violations of (common-sense) part-whole relationships, and is also used to demonstrate the bankruptcy of Humean supervenience. OSR builds *from* such empirical cases used to develop the concept of holism *to* a more general metaphysical view: that individuals are contextual, and that relational structure is prior to objects or entities (*qua* individuals). OSR, in other words, attempts to handle more than just non-separability and entanglement; it attempts to account for the concept of the "field" in relativity and QFT (i.e., that there can be no "rigid bodies"), the frame-dependence of many seemingly "intrinsic" properties of "objects" like mass and electric charge, the relativistic equivalence of mass-energy, the phenomenon of plasmas, quantum liquids, etc. We may therefore see OSR as the more general of the views.

OSR and fundamentalism. OSR rejects many fundamentalisms: levels and laws fundamentalism being the two most obvious. The former says that the universe is (metaphysically) arranged in a hierarchy of levels, according (roughly) to size/scale, from the subatomic to the atomic, molecular, etc. and that physics provides the most fundamental level from which all other levels might be derived or in any case upon which all higher levels *ontologically depend* (we may weaken this by saying "upon which all higher levels *supervene*, where supervenience is a kind of logical dependency relation between the levels). The latter holds that the universe *unfolds* or is *produced* from laws of nature; that the universe evolves as a consequence of some fundamental physical law(s), from one state to the next, given the initial conditions present at its initial stage of evolution (the view of Maudlin). Laws are on this view, therefore, *ontologically primitive*. Levels fundamentalism is a thesis of the Humean and it advocates for a *synchronic determination* between the levels, whereas laws fundamentalism is a thesis of the non-Humean (in Maudlin's formulation of the position) and advocates for a *diachronic* determination between *successive states* of the universe-at-a-time (the question of the synchronic relations between levels, presumably, is open: one could adopt a kind of ontological emergence—a decidedly anti-Humean position—on this score, while maintaining laws fundamentalism). OSR rejects levels fundamentalism: it is an open question as to whether or not "fundamental theories" may be derived from "higher levels" of scale. Some (e.g. Robert Laughlin) have argued, for example, that general relativity may be *derivable* *from* condensed matter theory—a theory that does not seem to be fundamental to general relativity because the latter entails as *solutions* to its differential equations the former (i.e., matter fields may be considered as solutions to the Einstein Field Equations[105]). The empirical relationships between different levels of scale is entirely open to investigation and of no ontological significance according to OSR. It is hard to see that OSR is compatible with laws fundamentalism: laws are descriptions of structure and as such their ontological status is parasitic on that structure; it is not clear that is makes sense to speak of the universe's "unfolding" according to OSR.

Mathematical vs. physical structure. OSR is not committed to there being an ontologically significant distinction between mathematical as opposed to physical structure. Notice that from the fact that the distinction has been rejected as carrying ontological weight, it would be wrong to thereby charge OSR with either reifying mathematics *or* with eliminating it in favor of physical 'natures' etc. That would be to beg the question against OSR. It is important to point out that we do not have a prior notion of mathematics to work with, just as we do not have a prior notion of "physical nature". The definition (as opposed to the *use*) of such concepts is dependent upon philosophical creativity, and the naturalized metaphysics adopted here simply

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[105] *See* for example Robert Laughlin (2005): *A Different Universe: Reinventing Physics from the Bottom Down.* This case is quite interesting because the claim on the table is that the laws governing condensed matter—laws which describe the behavior of *quantum mechanical* phenomena like Einstein-Bose condensates and quasi-particles (non-elementary "particles" that are non-individuals and are theorized to have fractionalized elementary charges), and effects such as super-fluidity—entail the laws of general relativity (i.e., a theory of *gravitation*). This seems to flip the ontological order on its head; though, arguably, with the advent of general relativity, it is not at all clear (ontologically speaking) whether it is gravity that describes matter, or matter that described gravity—the spacetime structure and the matter fields are in the case equivalent according to GTR. But, it is certainly not true that GTR implies matter fields which, e.g., obey Einstein-Bose statistics—a characteristically quantum mechanical fact. That is, GTR has yet to be consistently related to quantum field theory, and the basic purport here is to do just that (thus, it constitutes in effect a kind of "quantum theory of gravity", albeit from the perspective of a theory of the nature and behavior of *matter*).

advocates that all *metaphysical concepts* be subject to, and dependent upon, actual scientific/empirical analysis. The concepts of common sense, of course, are another matter. We might relegate the entirety of "ordinary language philosophy" (i.e., most of philosophy in the Anglo-American community) to this category, the category of analytical precision with respect to the ordinary use of concepts. This has its own domain of applicability, and as we filter our commonsense notions through our empirical traditions, we discover the extent to which those concepts are useful and the extent to which they require revision or expansion. As science has demonstrated, though, most of our commonsense notions must be given up *from the point of view of science, especially fundamental physics*[106]. The question as to what mathematical structures "are" is, according to OSR, simply a species of the question as to *what structure there is in the world at all*. That is, mathematical structures are "physical structures" insofar as they become part of the language of empirical inquiry (fundamental physics and the special sciences). Whether or not the structures "exist" or are "referred to" is another matter. OSR says we simply don't know whether "they exist". Furthermore, asks OSR, why does there have to be a referent of a concept? Isn't it enough that we may learn to use it, and write down a system that explicates the mathematics so that another person may in turn learn it, commit it to memory in

[106] Notice the assumption here is that 'ordinary' means 'ordinary'. Ordinary means, roughly, "not philosophically analyzed". It is not sufficient, for example, to defend the concept of 'ordinary objecthood' with a notion of 'primitive-thisness' etc. The idea of the analytical metaphysician in this case is that we must find a philosophical ground that provides support for the concept, and invent philosophical concepts for this purpose (another example would be the case of "fictional objects"). This leads to un-natural metaphysics insofar as no part of the analysis rests on empirical premises. The whole process is devoted to the establishment of ordinary use in philosophical analysis. I wholly reject this, and OSR is not committed to this sort of philosophical dialectic (cf. Ladyman *et al.*'s "primacy of physics constraint" and their "principle of naturalistic closure").

part, and then use it, and so on[107]. Perhaps some concepts—some mathematical structures—simply *do not refer*, and whether or not they do is something that *is an open empirical question* (taking "reference" to be "corresponds to the structure of nature").

"The" Structure? OSR is not committed to the existence of there being a real "totality" or whole "composed of" structure. This would constitute what Russell called an "illegitimate totality". OSR says that there is relational structure "all the way through", but this does not bottom-out or top-off.

2. Main objections and replies. There are a host of closely related objections to structural realism that I'd like to consider now. They are centered around a couple of main issues. One issue is whether or not there is a tenable distinction between 'structure' and 'non-structure' (the latter itself open to numerous possibilities: entity, nature, object, substance, property, individual, etc.). In other words, exactly *what* distinction, if any, is required to make metaphysical sense of *structural* realism and is

[107] The underlying thesis here requires a distinction between two sorts of mathematics: there is the mathematics that is, or has been, incorporated into a science or other empirical practice (it might even constitute *most* of the practice, as with theoretical physics), and there is the mathematics that is part of a living practice for no end but the doing of mathematic itself (with contemplative and non-contemplative aspects), the mathematics of which is not necessarily associated with the former, empirically oriented kind. Thus, my thesis here is that mathematics learned and used and contemplated is neither "in the head" or purely abstract, nor "in the world" or purely concrete. It is, in effect, a "distributed system" of learning, both individual and social, and memory, both individual, community and cultural. But when we speak of the mathematics of the sciences or physics, and say that it captures the structure of (some aspect of) nature, we do not mean not the living practice sort of mathematics. We now refer to mathematical structures which have been found to be applicable to the natural world. And this discovery is akin to the discovery that the map you have been using and contemplating actually allows you to get around in your immediate surroundings and *possibly beyond*. Now, both sorts of mathematics may themselves be open to a structural description: in the former case the structure will not be purely limited to the domain of physics, etc. The structure of relationships between the contemplative activity, the community of mathematics users and teachers, the books your read, etc. all provide a structure at another level of description that is simply more general than, and at any rate *not narrow enough*, relative to the mathematical structures employed in science. To suggest that structural realism must provide a substantial distinction between mathematical structures and those that are employed in physics seems to be to asking the structuralist to commit a category error.

it tenable? Another main issue (related to the one above) has to do with representation of structure (to which the structural realist wants to be metaphysically committed), in particular with the question of whether we should take theories to be linguistic constructions or not, and how a theory can be understood to reflect the (real) structure of nature as opposed to (and this harkens back to the first issue) the often historically contingent entities, properties, etc. referred to in past (and present) scientific theories. Indeed, the deeper question for structural realism is whether we are committed to anything *beyond* the purely mathematical and structural relationships *of a theory*; and if so, what? In other words, does structural realism threaten to collapse into either a version of strict empiricism or a kind of Platonism? My hypothesis is that *properly understood*, the structural realist might want to commit to *both* horns of the dilemma—properly understood. We shall see.

Reply to the Newman-Demopoulos-Freidman problem. One reply open to the structural realist against the "Ramsey-sentences" problem, raised by Demopoulos and Freidman (1985), which follows Newman (1928), is to deny the assumption that allows the Ramsey tactic to apply in the first place: namely, that theories are linguistic constructions, where the formal, logical relations *between* the theoretical terms of a theory are taken to be the only knowable reality. As Demopoulos and Freidman rightly pointed out, this is quite trivial, since on this view all that we can know is a collection of relations up to isomorphism, telling us very little. They write, citing Newman:

> The difficulty is with the claim that only structure is known. On this view "the world consists of objects, forming an aggregate whose structure with regard to a certain relation R is known, say [it has structure] W; but of . . . R nothing is known . . . but its existence; . . .

> all we can say is *there is* a relation R such that the structure of the external world with reference to R is W" (Newman 1928, p. 144). But "any collection of things can be organized so as to have the structure W, provided there are the right number of them"…. Thus, on this view, only cardinality questions are open to discovery! (Demopoulos and Friedman, p. 627)

Surely this is empirically bankrupt, and at any rate not how science proceeds. This seems to put the cart before the horses.

As McArthur (2006) points out in his survey of some recent debates over structural realism, Ladyman (1998) has replied that this objection only applies to the *epistemic* structural realist, whose position is that "nothing can be known of unobservables other than the structural relations that they engage in as expressed in a theory's Ramsey sentence" (McArthur 2006, 217). As for the *ontic* structural realist (which McArthur dubs the "metaphysical" structural realist), things are the other way around: structure is metaphysically primitive, rather than objects and their relations[108]. It is not that only structure is known; (relational) structure *is* what is

[108] For the epistemic structural realist, the objects and their relations are taken to be the needed, though unobserved, "substratum" or "things in themselves" of which we only have *structural* knowledge. There is clearly tension in this view, as Kant in effect pointed out long ago: according to this view, our knowledge *depends* on this substratum, yet we cannot "directly" access it; we only have knowledge of structure among the things in themselves. Importantly for the ontological structural realist, there is not much to the "observable"/"unobservable" distinction, for as our capabilities in both perception and theorizing are extended—that is, as our thought becomes increasingly mediated and therefore supplemented by technologies of various kinds, both external to thought (telescopes, computers, particles accelerators) and internal to it (logic and mathematics)—such a boundary becomes increasingly arbitrary and altogether irrelevant. To put the point in another way: both the apparatus of technology in the sense of devices we create and then interact with in the external world, and the apparatus of what we might call "mental" technology or technology of thought as we have though mathematics and logic, provide us ways of extending what we can "see", i.e., *understand*. We may, indeed, take this process of extending knowledge with these various technological supplements as another kind of real relationship, an epistemic one, into which human beings enter when knowing the physical world. But it is wrong to judge from the fact that we must depend on certain relations for our knowledge that our knowledge is therefore of structure only, rather than "things in themselves" for this is not quite accurate to the way knowledge actually proceeds (I here reject the primacy of a "rational reconstruction" of knowledge from science, or of a sharp distinction between "context of justification" and "context of discovery"). What we call "thing in itself" is merely our ignorance of a *deeper level of structure to nature in some domain of empirical inquiry, relative to what structure is already known*.

being described by theories. We may then isolate features of the structure described by a theory and in turn derive a notion of object, etc. but such entities are *derivative from a prior ontology of structure.* Hence, rather than beginning with the logic of predicate calculus or more generally with set theory, one ought to choose a representational scheme that takes ‘relation’ as a primitive (unanalyzed concept), out of which one might construct the notion of ‘object’ and ‘relation between object’ as *derivative concepts*[109]. This would, if successful, allow the ontic structural realist to express, formally, the commitment to ontologically primitive structure (where the structure is taken to be “relational structure”, following Ladyman *et al*. 2007). Ladyman (1998) proposed to adopt, consequently, a “no-statement” view of theories where theories are taken to be collections of models and not linguistic entities (i.e., sets of sentences, which would be clearly representable with the predicate calculus,

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That is, knowledge is always proceeding to more and deeper and even more abstract levels of structural knowledge, so that the postulation of a “thing in itself” is always unnecessary. It is a fiction which may be unproblematically given up. What distinguishes structures from one another is their *use* and effective correspondence between representational structure and non-representational structure (i.e., “nature”, of which the representational structures are but one part, i.e., in the mind of the theorist, or in the paper-and-pencil description, or in the models of a computer program).

[109] There is a longer historical and philosophical argument to be made here that the rise of modern abstract algebra (of which group theory is a species) represents a move towards precisely the view that ‘relation’ is primitive, on the basis of which you may construct an algebraic structure that represents certain mathematical concepts (“rotation”, etc.) which, on this algebraic basis, may be considered as conceptually independent of the particular details of what “realizes” or “instantiates” that structure (coordinate systems, various sets of numbers, etc.). Indeed, the symbolic character of abstract algebra has this feature to it: the symbols may represent may different mathematical “objects”, yet nonetheless the algebra captures a more general—i.e., invariant—feature of those objects which is a certain abstract structure. In order to demonstrate that such objects (upon which relations are thought to depend) are mathematically unnecessary for the conceptualization of algebraic structures, we might try to provide a foundation for abstract algebra where the objects *themselves* are given in relational or structural terms. There is a mathematical tradition, “graph theory”, that does this already (though not necessarily in the context of abstract algebra), and there are so-called “pointless” topologies, and so on. The point, so to speak, is that ‘object’, on which ‘relation’ is conceptually dependent, needn’t be taken, mathematically speaking, as a primitive. Notice that the claim here, again, is not that “objects or the relata standing in a relation” do not exist; rather, the claim is that the objects or relata are *derivative from* a more fundamental concept, that of ‘relation’, which is taken to be itself conceptually primitive. As such, the thesis is decidedly not incoherent; it merely rests on a subtle claim of “logical priority”, the tenability of which claim depends on whether or not there *always exists* a relational analysis of ‘object’ or ‘relata’. There does not seem to be any *a priori* reason to doubt this, logically or mathematically.

on the basis of which the Ramsey-sentence tactic is based). This model, non-linguistic view of theories, proposes Ladyman, could be cast with group theory, for which one could find a variety of linguistic representations. The question, however, is whether or not this twin move—taking structure to be ontologically primitive and adopting a representational scheme where 'relation' is conceptually and logically prior to 'object' and relata—would *also* obviate the Ramsey-sentence problem. I think there is more to their objection than the formal question it raises, which is: can we restate structural realism in such a way as to not be reliant upon a logic or formalism where relata are basic, and relations derivative? This requires a reconsideration of the objections raised by Demopoulos and Friedman.

It seems to me that the deeper problem posed by Demopoulos and Friedman is that it is possible to have two or more *structurally identical* collections of things, where in each set the things are arranged differently (say, spatiotemporally), and where those different arrangements *of the things* might make all the difference! Or, perhaps worse, I can have two sequences of the *same* thing which have the same structure but which are still different from each other. Consider, for example, a perfectly spherically symmetric ball travelling a spacetime path from point A to point B to point C. Now consider the same object in a time-reversed sequence: point C to point B to point A. Suppose that there are no other objects in the vicinity of the moving object, and that by points A, B, C I refer to equally spherically symmetric objects that serve as markers for the spacetime path (i.e., by 'path' I mean the sequential intersection of the object with other objects at A, B, C). Taking, for the moment, temporal asymmetry to be a fact about the world and not just a feature of my perspective on it[110], these two cases—time-ordered sequence #1 consisting of {A,B,C} and time-ordered sequence #2 consisting of {C,B,A}—are different states of the world (going from Earth to Mars, or going from Mars to Earth), yet they are *structurally identical*. Physics does not explicitly put in this directionality, yet it is a plausible feature of our world, if not of my experience of it. So, one might add, perhaps as Maudlin would, the *extra* ingredient of an arrow of time, in which case we can easily break the structural identity. So, the bare theoretical structure does not tell us enough about the world; there seems to be more to it. The theoretical structure allows me, certainly, to *represent* the world (the trajectory of a moving object), but the theoretical structure itself leaves out something, i.e., the *movement of the object through space and time, from one point to another*.

Firstly, the problem of the arrow of time is not particular to structural realism; it is an issue faced by anyone who contemplates the significance of physics and the laws of nature. Ladyman and the structural realist might reply to this specific charge by simply pointing out that if, as in the case above, an aspect of the world (or our experience) is left out of a theory, then that is a problem with the theory and not with structural realism per se. In other words, if it's not part of a theoretical description in the first place, then it's obviously not going to appear in a structural interpretation of it. Furthermore, the claim of the structural realist *here* is simply that *should* a feature of reality be captured (or be represent*able*) in some theory, and should that theory be understood in terms of a collections of models (i.e., non-linguistically), then it is possible to provide a structural realist interpretation of the theory. That this is *always*

[110] This is, for example, Maudlin's thesis, defended at length in his 2008.

possible is another matter (we might provide a bit of logical analysis here for this question), one which does not need to be resolved here. One other important aspect of this objection is the distinction between what a theory represents *versus* what there is about the world independent of our theoretical representations of it.

Objection: the distinction between the mathematical representation of structure and that which is being represented reduces to the 'structure' vs. 'nature' distinction. The ontological structural realist says that structure is ontologically prior to objects or the relata standing in any relation, and that this is what a theory faithfully captures. But then what is the distinction between the mathematical representation and that which is represented? I think that this objection has no force to it. The distinction can be rephrased so as to alleviate the worry that it collapses to, or otherwise relies on, the untenable distinction between 'structure' and 'nature'. We may state the distinction simply as that between a *mathematical representation of* structure and the *structure that is not representational at all*—i.e., the structure of nature "itself". As French and Ladyman point out, "to describe something using mathematics does not imply that it is itself mathematical (2003b, 75 as cited in McArthur 2006, 218). This does not, as McArthur contends, threaten to run amok of Psillos' objection that structural realism is committed to an untenable distinction between 'structure' and 'nature' i.e., to the "distinct but inexpressible in-itself" (McArthur, *ibid.*). The problem is simply that we want to know, so to speak, "where" the mathematical structure is and "where" the structure of nature is. The answer to these questions is simple, and allows us to unproblematically distinguish between "nature" or "physical structure" as opposed to "purely mathematical": the mathematical structure is simply "in" my paper-and-pencil markings, or “in” a computer program, or “in” the acts of generating a theoretical model. Such things are certainly part of the “physical structure of the world”, but they are just sub-structures within a larger physical structure which correspond to an aspect of that larger physical structure. But there is no substantial *ontological* distinction here between the “paper-and-pencil” structures (or the mathematical concepts in my head) and the “physical” structures to which these structures correspond. The point is that I may say that a map corresponds to the physical world, but the map does not have to represent me as well; I can always generate a *larger* structure of relationships which then *also represents me in relation to the structure of the map*, and so on. But surely there is no deep metaphysical problem because the map does not itself contain a reference to its user. So, mathematical structures—graphs, pencil markings, computer readouts, etc., are simply substructures within a larger structure (“the world”), the relation between the substructure and some whole of which it is a part I may always characterize in structural terms.

“Constructive Empiricism” and Structural Realism: a challenge? Van Fraassen (2006, 2008) has argued extensively that, if we re-construe structural realism along the lines of constructive empiricism, we arrive at a position van Fraassen calls “empiricist structuralism” (van Fraassen 2006, p. 299ff) and on his view the metaphysical bite goes away. He summaries his view as follows:

> Science represents the empirical phenomena solely as embeddable in certain abstract structures (theoretical models), and those abstract structures are describable only up to structural isomorphism. […] There is warrant for the assertion of an accumulation of empirical knowledge through theory change precisely if it can be demonstrated for phenomena counted among the empirical successes of earlier

> science that, if they are embeddable in the new models then they are 'approximately' embeddable in the old models. (p. 305)

Clearly, van Fraassen wants to satisfy the "no miracles" intuition *and* speak to the "pessimistic meta-induction" in a manner consistent with constructive empiricism. Empiricist structuralism is a position that purports to account for the success of science and for aspects of theory change that the structural realist is concerned with, without being committed to a metaphysics of theoretical entities *or* being committed to (ontological) structure. *No* metaphysics! Science is "about" empirical phenomena—that which is observed. Van Fraassen continues:

> This empiricist re-construal is scant comfort to the scientific realist, of course. It also sets aside as unimportant the conceptual puzzles about how to distinguish structure from content or quality, which beset so-called structural realism. But it provides a balanced view of scientific theory change, taking some of the mystery out of scientific revolutions. All it takes, to achieve this more balanced view, is to dispel the lazy illusion that we could do this by means of the simple expedient of either reifying the models or regarding them as delineating the objective structure of a hidden qualitative content. (*ibid.*)

It is important to point out that van Fraassen's view simultaneously avoids both epistemic *and* ontic versions of structural realism: science is only about the *representation of empirical phenomena*; it is where knowledge of empirically adequate theoretical knowledge is gradually accumulated through the centuries, which knowledge is grounded solely in acts of human observation and intellectual ingenuity. Metaphysics, insofar as it steps beyond the horizon of empirical adequacy, is unneeded to adequately account for the success of science. This success is to be measured in proportion to how adequately theories save the phenomena. Arguing against the very motivation of Worrall, van Fraasen writes:

> The empirical success of the older theories were partial successes of a very distinct sort: their representations of nature, the models they made available for representation of the observed phenomena, were partially accurate. These successes consisted in their fitting the data, the deliverances of experimental and observational experience. There was something they got right: the structure, at some level of approximation, of those phenomena. Here the word 'structure' is used to point specifically to a certain character, defined by certain measureable parameters both old and new theory use to describe those successes. … Just look at those empirical phenomena! (*ibid*., p. 304)

From science, we need no more and can do with no less. Such a view provides no *metaphysical foundations* for science. Warns van Fraassen, we must "prevent ourselves from sinking into [a] metaphysical morass that swallows all seekers for the true foundations of being", i.e., metaphysics (*ibid.,* p. 303).

A (polemical) reply to van Fraassen: the aims of metaphysics and the goal of philosophy. It is part of van Fraassen's thesis that, prior to any conception of science, we must distinguish between the phenomena that a theory attempts to describe, and the abstract representational apparatus of theories. Philosophy, at this stage, may help us to sharpen this question, but need not supply a "theory" (an *a priori* account) to settle the matter. More importantly for van Frasseen: science is only in the business of adequately accounting for the phenomena, that is, providing us with relatively accurate model-representations of "experimental and observational experience". That a model is successful *does not imply the existence of unobservable* theoretical entities. That Maxwell's theory provided an accurate description of electric and magnetic phenomena does not imply the existence of some ontological "thing" that "underlies" the phenomena. Rather, Maxwell's equations provide us with a means of finding models that represent/describe very well what is detectable and observable, and may even allow us to locate other, as-yet unknown, instances of the *same phenomena*. Postulating something else—a field—*reifies* the models science provides. Alternatively, we may say that the equations describe the form or *structure* of something, an unknown entity (van Fraassen 2006, p. 279).

Notice, though, that the thesis defended throughout this dissertation, and the thesis of Ladyman *et al*. provides *yet another* alternative that is neither reification nor the "form" or structure of "some unknown entity". In particular, the thesis defended here asserts that individuals are contextual in the sense that their existence at any moment is causally and non-causally dependent upon conditions whose absence implies the absence of the individual. If entities are individuals, then entities are contextual as well. Additionally, insofar as science and fundamental physics implies the contextuality of individuals, there are no good grounds to defend the thesis that individuality is grounded in anything other than relational structure. That is, entities are ontologically secondary to relational structure in the sense that the former are derivative from (or ontologically dependent upon) the latter. 'Structure' here refers to the larger modal context in which we locate individuals, and by 'modal context' I mean a structure of inter-dependencies (both causal in the standard sense and non-causal). By ontic structural realism I mean that 'structure is all there is' in the sense that individuals within a structure are themselves just more structure, and that "it's structure all the way down". There is no *thing* or *substance* that is structure *precisely because* of the (i) contextuality of individuals and (ii) there is no "lower-most" or "upper-most" level of structure. That is, structure is not a "totality" (such a notion would be illegitimate), it has no substance *itself*, and it is open-ended. In fact, we should not even use the term "it" to designate "it"—there's not "it"! Science reveals to us a widening scope of empirical interrelationships; some fields of science are isolated to a particular level of scale (quantum field theory and particle physics), while others may study and describe *interlevel* relationships (*between* the quantum and general relativistic scale-levels of the universe, for example). Structural realism is a metaphysics but not one of the substance or form-of-we-know-not-what varieties. As defended here, it is not committed to a kind of Kantian enclosure within phenomena; it is not of the much-maligned "epistemic" sort. The version of structural realism defended in this dissertation needs, therefore, to be labeled something else, as something outside the standard metaphysics/epistemology categories, associated as they are with the boogeyman of "realism" vs. "nominalism"—precisely the views "constructive empiricism" is cooked up to avoid.

I would like to concede much to van Fraassen's "empiricist structuralism" in fact. Most of what he defends is friendly to the ontological structural realist, in my view. The difference—perhaps what is the most significant difference, and what puts the thesis somewhat off the present map—is that I do not conceive of the project of "metaphysics" in the way that van Fraassen does. I, rather, adopt the view of William James (1911):

> In its original acceptation, meaning the completest knowledge of the universe, philosophy must include the results of all the sciences, and cannot be contrasted with the latter. It simply aims at making of science what Herbert Spencer calls a "system of completely unified knowledge". In the more modern sense, of something contrasted with the sciences, philosophy means "metaphysics". The older sense is the more worthy sense, and as the results of the sciences get more available for co-ordination, and the conditions for finding truth in

> different kinds of questions get more methodically defined, we may hope that the term will revert to its original meaning. Science, metaphysics, and religion may then again form a single body of wisdom, and lend each other mutual support.
> At present this hope is far from its fulfillment (from *Some Problems of Philosophy*).

In light of James' view, we should dub the view of metaphysics adopted in this dissertation as "coordinative metaphysics", as opposed to "ordinary language" metaphysics or "substance metaphysics", and as opposed to "constructive empiricism", positivism and metaphysical agnosticism. This, finally, is the fourth tradition of philosophy. It is a sound attempt to escape being committed to "the true story", for structure is not "the truth" about "being" or reality. Reality and being are the *inputs* to such a view, *not the doctrinal outputs*. Structural realism is a method, not so much a doctrine. It is a proposal—much like we may take the Cartesian Coordinate System—for how to organize our empirical discoveries *into a coherent whole*. It is a view that attempts to unify not through a substance or through a conceptual analysis, but through the investigation of the empirical relationships that might exist irrespective of scale, ontological preferences or hierarchies, and so on. It is not concerned with "truth", but, as with van Fraassen's constructive empiricist, empirical adequacy *in light of a coordinative view of the relationship between all empirical facts, at once*.

Science, indeed, need not be committed to any theoretical entities *because it reaveals to us a gradually widening scope of structural relationships.* We understand "thing" from two points of view: from the point of view of all of science and empirical knowledge (and the commonsense concept here is woefully inadequate, and our coordinative metaphysics requires an appropriately wide and revised conception, without the introduction of metaphysical entities, etc.—an Occam's Razor certainly applies here). It attempts a "panoptic" view of all the sciences, a *coordinative sight*. But it is an attempt to first rid philosophy (or science) of prejudice, of taking a particular view as to the "true" structure or nature or make-up of reality. It is an attempt to clear the way for *whatever empirical connections there might be in the world*, irrespective of our philosophical doctrines: behaviorism, materialism, physicalism, substance-dualism, and so on. *All* such positions are, indeed, fruitless and built upon philosophical castles in the sky. We might, wonders the structuralist, discover all sorts of strange things about our universe. But all of these things, insofar as we can observe and study them, will be describable, and will count as *part of the same world*. One fabric with many interrelated strands, each sub-strand of which is yet another interrelated pattern of strands … and so on forever. Science should proceed *without limit* and without bias. It is open, and ought not be weighed down by philosophical doctrines that have dogged many a philosopher and tradition of the past (scholasticism, the Kantian tradition, the Hegelian tradition, positivism, etc.). Presently, mathematics offers the most precise representational apparatus man has yet devised, but there is no reason to think that mathematical representations are the only powerful and meaningful empirical tools man might use; nonetheless, technological augmentations of humanity's empirical inquiry are likely here to stay and will likely aid us in reaching ever greater interiors of the cosmos.

Appendices

APPENDIX 1. Stuckey, Silberstein and Cifone (2008a), *Foundations of Physics* 38 (4): 348—383.

Reconciling Spacetime and the Quantum: Relational Blockworld and the Quantum Liar Paradox

W.M. Stuckey[1], Michael Silberstein[2,3] and Michael Cifone[3]

Abstract

The Relational Blockworld (RBW) interpretation of non-relativistic quantum mechanics (NRQM) is introduced. Accordingly, the spacetime of NRQM is a relational, non-separable blockworld whereby spatial distance is only defined between interacting trans-temporal objects. RBW is shown to provide a novel statistical interpretation of the wavefunction that deflates the measurement problem, as well as a geometric account of quantum entanglement and non-separability that satisfies locality per special relativity and is free of interpretative mystery. We present RBW's acausal and adynamical resolution of the so-called "quantum liar paradox," an experimental set-up alleged to be problematic for a spacetime conception of reality, and conclude by speculating on RBW's implications for quantum gravity.

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Key Words: blockworld, non-relativistic quantum mechanics, entanglement, non-locality, measurement problem, quantum liar paradox

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1. INTRODUCTION

Many philosophers and physicists expect to find new physics lurking in the answer to van Fraassen's[1] foundational question par excellence: "*how could the world possibly be the way quantum theory says it is?*" In fact, Smolin[2] believes that what "we are all missing" in the search for quantum gravity "involves two things: the foundations of quantum mechanics and the nature of time." We share this sentiment and are therefore motivated to "understand" non-relativistic quantum mechanics (NRQM). As we will show, our interpretation has strong implications for the practice and unification of physics, and we will speculate formally on these consequences.

Since there are several well-known conceptual and formal tensions between relativity and quantum mechanics which bear on the project of unifying general relativity (GR) and quantum field theory (QFT), we feel that a necessary condition for "understanding" NRQM is to couch it in space and time as required for "comprehension" per Schrödinger[3],

> This contradiction is so strongly felt that it has even been doubted whether what goes on in an atom can be described within the scheme of space and time. From a philosophical standpoint, I should consider a conclusive decision in this sense as equivalent to a complete surrender. For we cannot really avoid our thinking in terms of space and time, and what we cannot comprehend within it, we cannot comprehend at all.

and Einstein[4],

> Some physicists, among them myself, cannot believe that we must abandon, actually and forever, the idea of direct representation of physical reality in space and time.

As Howard notes in the following passage, one of the central debates between the founding fathers of quantum mechanics was over the conflict between the spacetime picture and the quantum picture of reality and how they may be reconciled[5]:

> The second striking feature of Pauli's last-quoted paragraph is that it points backward to what was by 1935 an *old* debate over the nonseparable manner in which quantum mechanics describes interacting systems. The fact that this was the central issue in the pre-1935 debate over the adequacy of the quantum theory disappeared from the collective memory of the physics community after EPR….Einstein had been trying in every which way to convince his

> colleagues that this was sufficient reason to abandon the quantum path…But it was not just Einstein who worried about quantum nonseparability in the years before 1935. It was at the forefront of the thinking of Bohr and Schrödinger.

In today's terminology we would say that the spacetime picture of relativity adheres to the following principles[(6)]:

> Separability principle: any two systems A and B, regardless of the history of their interactions, separated by a non-null spatiotemporal interval have their own independent real states such that the joint state is completely determined by the independent states.
>
> Locality principle: any two space-like separated systems A and B are such that the separate real state of A let us say, cannot be influenced by events in the neighborhood of B.

It is now generally believed that Einstein-Podolsky-Rosen (EPR) correlations, i.e., correlated space-like separated experimental outcomes which violate Bell's inequality, force us to abandon either the separability or locality principle.

As Howard notes, Einstein thought that both these principles, but especially the latter, were transcendental grounds for the very possibility of science. Einstein's spatiotemporal realism is summarized in his own words[(7)]:

> Is there not an experiential reality that one encounters directly and that is also, indirectly, the source of that which science designates as real? Moreover, are the realists and, with them, all natural scientists not right if they allow themselves to be led by the startling possibility of ordering all experience in a (spatio-temporal-causal) conceptual system to postulate something real that exists independently of their own thought and being?

Minkowski spacetime (M4) is a perfect realization of Einstein's vision but as Howard says[(8)]:

> Schrödinger's introduction of entangled n-particle wave functions written not in 3-space but in 3n-dimensional configuration space offends against space-time description because it denies the mutual independence of spatially separated systems that is a fundamental feature of a space-time description.

And we might add that realism about configuration space also destroys Einstein's vision of spacetime as the be-all and end-all of reality as exemplified by M4.

All of this raises an interesting question about just how much of the spacetime picture can be retained given quantum mechanics. As we will show, the Relational Blockworld[9] interpretation of NRQM points to a far more intimate and unifying connection between spacetime and the quantum than most have appreciated. Many will assume that such a geometric interpretation is impossible because quantum wavefunctions live in Hilbert space and contain much more information than can be represented in a classical space of three dimensions. As Peter Lewis says[10], "the inescapable conclusion for the wavefunction realist seems to be that the world has $3N$ dimensions; and the immediate problem this raises is explaining how this conclusion is consistent with our experience of a three-dimensional world." On the contrary, the existence of the non-commutativity of quantum mechanics is deeply related to the structure of *spacetime* itself, without having to invoke the geometry of Hilbert space. Specifically, as will be demonstrated in section 2, the non-commutativity of NRQM's position and momentum operators *is a consequence of* the relativity of simultaneity. Since, as will also be demonstrated in section 2, the NRQM density operator can be obtained from the spacetime symmetries of the experimental configuration, we justify a Relational Blockworld (RBW) interpretation of NRQM.

1.1 Caveats. It is important not to be misled at this early stage by our claim about the spacetime symmetries of the experimental configuration. We are not advocating a brute spatiotemporal relationalism between sources and detectors, themselves conceived as classical and substantial trans-temporal, macroscopic objects. Rather, it's "relations all the way down" to echo Mermin. The spacetime symmetries methodology of NRQM is just the beginning of our account wherein "it is all related" because "it is all relations." That is, on our view any given relatum (such as a source or detector) always turns out to be a relational structure itself upon further analysis. The formal characterization of relations will change accordingly as we move toward the more fundamental relations underlying RBW (as introduced in section 2), but at the level of experimental set-ups in NRQM, spacetime symmetries are the most appropriate characterization of relations (as illustrated in section 4). In short, relationalism does not end with macroscopic objects but applies to their ultimate "constituents" as well.

The reader is warned that RBW is counterintuitive in many respects. Of course there are many interpretations of quantum mechanics that have highly counterintuitive features, but RBW possesses its own unique twists on several such features. Primarily, these counter-intuitive aspects arise from: (1) our claim that relations are fundamental to relata and (2) our particular variation of the blockworld.

1.2 Relations Fundamental to Relata. Assuming relations are fundamental to relata is not

unique to RBW. For example Carlo Rovelli's relational interpretation of quantum mechanics[11] holds that a system's states or the values of its physical quantities as standardly conceived only exist relative to a cut between a system and an observer or measuring instrument. As well, on Rovelli's relational account, the appearance of determinate observations from pure quantum superpositions happens only relative to the interaction of the system and observer. Rovelli is rejecting absolutely determinate relata. Rovelli's relational interpretation of NRQM is inspired by Einstein's theory of special relativity in two respects. First, he makes the following analogy with special relativity: relational quantum mechanics relativizes states and physical quantities to observers the way special relativity relativizes simultaneity to observers. Second, Einstein does not merely provide an interpretation of the Lorentz formalism, but he derives the formalism on the basis of some simple physical principles, namely the relativity principle and the light postulate[12].

Another closely related example is Mermin's Ithaca interpretation[13] which tries to "understand quantum mechanics in terms of statistical correlations without there being any determinate correlata that the statistical correlations characterize[14]." According to Mermin, physics, e.g., quantum mechanics, is about correlations and only correlations; "it's correlations all the way down." It is not about correlations between determinate physical records nor is it about correlations between determinate physical properties. Rather, physics is about correlations without correlata. On Mermin's view, correlations have physical reality and that which they correlate does not. Mermin claims that the physical reality of a system consists of the (internal) correlations among its subsystems and its (external) correlations with other systems, viewed together with itself as subsystems of a larger system. Mermin also claims inspiration from special relativity.

RBW shares with the relational and Ithaca interpretations a rejection of the notion of absolute states and properties. RBW also shares inspiration from relativity but as we shall see, RBW provides a much deeper and more unifying relationship between quantum mechanics and special relativity than the relational or Ithaca interpretations. In addition, both formally and conceptually, the characterization of relationalism in RBW is quite different than either of these views.

First, in terms of specific formalism, RBW employs spacetime symmetries and relations fundamental to those symmetries best characterized *as a* mathematical co-construction of things, space and time (explained in section 2). Second, the rubric characterizing relationalism is ontological structural realism(15) (OSR), which rejects the idea that reality is ultimately *composed of things*, i.e., self-subsisting entities, individuals or trans-temporal objects(16) with intrinsic properties and "primitive thisness," haecceity, etc. According to OSR the world has an objective modal *structure* that is ontologically fundamental, in the sense of not supervening on the intrinsic properties of a set of individuals. In Einstein's terminology, given OSR, particles do not have their own "being thus." The objective modal structure of the world and the abstract structural relations so characterized are fundamental features of reality relative to *entities* such as particles, atoms, etc. This is not anti-realism about objects or relata, but a denial of their fundamentality. Rather, relations are primary while the things are derivative, thus rejecting "building block" atomism or Lego-philosophy. Relata inherit their individuality and identity from the structure of relations. According to RBW, entities/objects and even the dynamical laws allegedly "governing things" are secondary to relational structure.

While the standard conception of structure is either set theoretic or logical, OSR holds that graph theory provides a better formal model for the nature of reality because relations are fundamental to nodes therein(17). Many people have argued that giving primacy to relations and abstracting relata from them is somehow incoherent.

However, graph theory shows us that such objections are prejudiced by atomistic thinking and ordinary language. In fact, per Leitgeb and Ladyman[18] the identity and diversity of individuals in a structure are primitive features of the structure as a whole in graph theory. Thus, we employ a spatiotemporal graph to provide a heuristic characterization of RBW in section 2.

What this implies for the quantum domain is that one must be cautious in using everyday classical metaphysics of individuality. For example, it is quite common for physicists to say things like, "I can see a glowing atom in the Pauli trap." RBW *a la* OSR does not deny such a claim so long as it is not meant to imply any "being thus" on the part of the atom, a metaphysical *interpretation* not entailed by the facts. Certainly, it is difficult to think about structure without "hypostatizing" individuals or relata as the bearers of structure, but it does not follow that relata are truly ontologically fundamental.

None of this is really new as OSR-type views have a long and distinguished history in foundational physics[19] and group theoretic accounts[20] of objects have a long history in the development of quantum mechanics. The group-theoretic conception of the 'constitution' of objects as sets of invariants under symmetry transformations can be found in the writings of Cassirer[21], Eddington[22], Schrödinger[23], Lyre[24], and Weyl[25]. When it comes to fundamental physics, objects are very often identified via group-theoretic structure, e.g., quantum field theory. So, while counterintuitive, the notion of relations being fundamental to relata is not without precedence.

1.3 The Blockworld. The second counterintuitive feature of RBW is the use of a blockworld (BW) in the explanation and interpretation of quantum mechanics. Thus, to appreciate the RBW ontology, one must appreciate the blockworld perspective[26], i.e.,

> There is no dynamics within space-time itself: nothing ever moves therein; nothing happens; nothing changes. In particular, one does not think of particles as moving through space-time, or as following along their world-lines. Rather, particles are just in space-time, once and for all, and the world-line represents, all at once, the complete life history of the particle.

When Geroch says that “there is no dynamics within space-time itself,” he is not denying that the mosaic of the blockworld possesses patterns that can be described with dynamical laws. Nor is he denying the predictive and explanatory value of such laws. Rather, given the reality of all events in a blockworld, dynamics are not “event factories” that bring heretofore non-existent events (such as measurement outcomes) into being. Dynamical laws are not brute unexplained explainers that “produce” events. Geroch is advocating for what philosophers call Humeanism about laws. Namely, the claim is that dynamical laws are *descriptions of regularities* and not the *brute explanation* for such regularities. His point is that in a blockworld, Humeanism about laws is an obvious position to take because everything is just “there” from a “God’s eye” (Archimedean) point of view. That is, all events past, present and future are equally “real” in a blockworld.

Others have suggested that we ought to take the fact of BW seriously when doing physics and modeling reality. For example, Huw Price(27) calls it the “Archimedean view from nowhen” and it has motivated him to take seriously the idea of a time-symmetric quantum mechanics and so-called backwards causation in quantum mechanics (BCQM). As he says about his book defending BCQM(28), “the aim of the book is to explore the consequences of the block universe view in physics and philosophy.” Price is attempting to construct a local hidden-variables interpretation of NRQM that explains quantum non-locality with purely time-like dynamics or backwards causation. According to Price, BCQM provides an explanation of the Bell correlations(29) “which shows that they are not really non-local at all, in that they depend on purely *local* interactions between particles and measuring devices concerned. They *seem* non-local only if we overlook the present relevance of future interactions.”

The key explanatory move that Price makes is to have information travel backwards along the light-cones of the two EPR particles, converging at the source of the entangled state. Presumably, this is the point in spacetime where the entangled state is “prepared.” The picture we must think of is this: the future measurement interaction in separate wings of an EPR apparatus is the cause of the (earlier) entangled state, so the "point at which they separate" is the "effect" of a causal chain "originating" with the measurement interaction. This is to put the point directly in terms of *backwards* causation. The arrow of causation does not point from one spacelike separated wing of the apparatus to the other, across *space*, but rather it points backwards in *time* to the point at which the particles separated. Other blockworld motivated accounts of quantum mechanics include those by Cramer[(30)], Lewis[(31)] and Barrett[(32)].

The connection between BCQM or time-symmetric accounts of the quantum and the BW is straightforward: in a BW the state preparations and measurement outcomes are equally real, i.e., already "there." Thus, since a dynamic interpretation of the BW picture is superfluous, one might as well claim the measurement outcomes "effect the state preparations" rather than the converse. Of course it may seem trivial to explain the outcomes of quantum experiments (or anything else) using the BW. After all, one could answer *any* question in this vein by saying something like "it's all just there in the BW, end of story." In order to avoid trivializing the BW explanation, BW interpretations of NRQM invoke clever devices such as time-like backwards causation[(33)], advanced action[(34)] and the two-vector formalism[(35)]. Do these beautiful and clever devices really avoid the charge of triviality? Such explanations are no less *dynamical* than standard quantum mechanics, which is puzzling given that the original blockworld motivation for such accounts lacks *absolute* change and becoming. As far we know, only Cramer speaks to this worry. Cramer notes that the backwards-causal elements of his theory are "only a pedagogical convention," and that in fact "the process is atemporal[(36)]." Indeed, it seems to us that all such dynamical or causal devices in a BW should be viewed fundamentally as book keeping. BCQM and the like, even having acknowledged the potential explanatory importance of BW, have not gone far enough in their atemporal, acausal and adynamical thinking. Whereas such accounts are willing to think backwardly, temporally speaking, it is still essentially *dynamical, temporal* thinking.

We rather believe the key to rendering a BW explanation nontrivial is to provide an algorithm for the relevant BW construction. Thus, the answer to "Why did X follow Y and Z?" is not merely, "Because X is already 'there' in the future of Y and Z per the BW," but as we will illustrate, "Because this must be the spatiotemporal relationship of X, Y and Z in the BW per the self-consistent definition of the entities involved in X, Y and Z." If one chooses to read dynamical stories from a BW picture, they may where feasible. However, BW descriptions are not limited to the depiction of dynamical/causal phenomena, so they are not constrained to dynamical/causal storytelling. In the following passage Dainton[37] paints a suggestive picture of what it means to take the BW perspective seriously both ontologically and explanatorily:

> Imagine that I am a God-like being who has decided to design and then create a logically consistent universe with laws of nature similar to those that obtain in our universe…Since the universe will be of the block-variety I will have to create it *as a whole*: the beginning, middle and end will come into being together…Well, assume that our universe is a static block, even if it never 'came into being', it nonetheless exists (timelessly) as a coherent whole, containing a globally consistent spread of events. At the weakest level, "consistency" here simply means that the laws of logic are obeyed, but in the case of universes like our own, where there are universe-wide laws of nature, the consistency constraint is stronger: everything that happens is in accord with the laws of nature. In saying that the consistency is "global" I mean that the different parts of the universe all have to fit smoothly together, rather like the pieces of a well-made mosaic or jigsaw puzzle.

Does reality contain phenomena which *strongly suggest* an acausal BW algorithm? According to RBW, the deepest explanation of EPR-Bell correlations is such an algorithm. NRQM *a la* RBW provides an acausal BW algorithm in its prediction of Bell inequality violations and these violations have been observed. So it appears that reality does harbor acausal BW phenomena and NRQM *a la* RBW is one algorithm for depicting the self-consistent placement of such phenomena in a blockworld, as will be illustrated via the quantum liar experiment in section 4.

We support this claim in section 2 by first reviewing a result in which the non-commutativity of NRQM's position and momentum operators is a consequence of the relativity of simultaneity, and as is well known the latter implies a blockworld barring some neo-Lorentzian adornment, re-interpretation or the like[38]. The second result reviewed in section 2 shows the density operator of an experimental configuration is obtained from the "past, present and future" of the entire spatiotemporal configuration *a la* the spacetime symmetries of the experimental set-up: from the initiation of the experiment to its outcomes (as is clear, for example, in the path-integral formalism). The blockworld as implied by the spacetime picture does real explanatory and unifying work in RBW. Thus RBW helps to unify the quantum and spacetime formally, conceptually and metaphysically in ways that neither other relational accounts nor BW-motivated accounts have to date. For all these reasons we claim that RBW constitutes a geometric, acausal and adynamical account of NRQM and spacetime that is fundamental to dynamical explanations. As Dainton says(39):

> If this strikes us as odd it is because we are unused to thinking of the universe as a vast spatiotemporal mosaic, but if the universe *is* a vast spatiotemporal mosaic, then, given the reality of the future, the future determines the past as much as the past determines the future. The constraints that later events place on earlier ones are not always causal [or dynamical or in any way time-like]. It is more typically a matter of coordination: the future events exist in the same universe as the earlier events, in a coherent, smooth-fitting, law-abiding whole.

1.4 Non-separability of Spacetime Regions and Quantum States. The blockworld of RBW is precisely in keeping with Geroch's "all at once" notion of spacetime and Dainton's "vast spatiotemporal mosaic," but it is important to note that it is a non-separable BW while that of relativity theory is separable. That is to say, the metric field of relativity theory takes on values at each point of the differentiable spacetime manifold, even in regions where the stress-energy tensor is zero, as if "things" are distinct from the concepts of space and time. Per RBW, the concepts of space, time and trans-temporal objects can only be defined self-consistently so each is meaningless in the absence of the others. In section 2, we suggest a method to formalize this idea, deriving a spatial distance defined only between interacting trans-temporal objects. Accordingly, there need not be an 'exchange' particle or wave moving 'through space' between the worldlines of trans-temporal objects to dynamically mediate their interaction and establish their spatial separation. As a consequence, we understand that an NRQM detection event (subset of the detector) results from a particular, rarefied subset of the relations defining sources, detectors, beam splitters, mirrors, etc. in an "all at once" fashion. In this picture, there are no “screened off” particles moving in a wave-like fashion through separable elements of the experimental arrangement to cause detection events, but rather such detection events are evidence that the experimental equipment itself is non-separable[111]. While non-separable, RBW upholds locality in the sense that there is no action at a distance, no instantaneous dynamical or causal connection between space-like separated events. And, there are no space-like worldlines in RBW. Thus, we have *the non-separability of dynamical entities, e.g., sources and detectors, while the entities themselves respect locality*. In this sense, we agree with Howard[(40)] that NRQM is best understood as violating “separability” (i.e., independence) rather than “locality” (i.e., no action at a distance, no super-luminal signaling), and we take to heart Pauli’s admonition that[(41)] “in providing a systematic foundation for quantum mechanics, one should start more from the composition and separation of systems than has until now (with Dirac, e.g.) been the case.”

One might perceive a certain tension in the combination of relationalism and the BW perspective. After all, nothing seems more *absolute* than the BW viewed as a whole, hence the Archimedean metaphor. One can just imagine Newton’s God gazing upon the timeless, static 4-dimensional BW mosaic (her sensorium) from her perch in the fifth (or higher) dimension; what could be more absolute? But relationalism is a rejection of the absolute and the very idea of a God’s eye perspective. In any case, one must never forget that while RBW is a blockworld in the sense that all events are equally real, it is a *relational* blockworld so there is no meaning to a God’s eye perspective, i.e., any beings observing the BW must be *a part of it*. Short of occupying all the perspectives “at once,” there is nothing that corresponds to such a privileged view.

1.5 Paper Overview. We offer a graphical model for this non-separable, relational blockworld in section 2. In support of our heuristic model, we introduce the formalism of RBW by outlining results due to Kaiser, Anandan, Bohr, Ulfbeck, and Mottelson, and speculating on a spatiotemporally discrete approach underlying

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[111] Since space, time and trans-temporal objects are to be mutually and self-consistently defined (via relations), the non-separability of spacetime entails the non-separability of trans-temporal objects and vice-versa. RBW does away with any matter/geometry dualism.

NRQM and QFT. We propose this spatiotemporally discrete approach both to follow up on the consequences of RBW for the practice and unification of physics, and to illustrate the RBW ontology. In section 3, we use this relational, non-separable blockworld to provide a geometric account of quantum entanglement and non-separability that is free of conflict with the locality of SR and free of interpretative mystery. Therein, we also show how RBW provides a novel statistical interpretation of the wavefunction that deflates the measurement problem. To illustrate the nature of explanation for NRQM phenomena in a relational blockworld, we use RBW to resolve the so-called "quantum liar paradox" in section 4. Speculations on the possible implications for quantum gravity and the spacetime structure of GR are found in section 5.

2. THE RELATIONAL BLOCKWORLD

The RBW interpretation of NRQM is founded, in part, on a result due to Kaiser[(42)], Bohr & Ulfbeck[(43)] and Anandan[(44)] who showed independently that the non-commutivity of the position and momentum operators in NRQM follows from the non-commutivity of the Lorentz boosts and spatial translations in SR, i.e., the relativity of simultaneity. Whereas Bohr *et al.* maintain a dynamical view of NRQM via the Theory of Genuine Fortuitousness[112], we assume the blockworld implication of the relativity of simultaneity so that no particular event is more fortuitous than any other. Kaiser writes[(45)],

> For had we begun with Newtonian spacetime, we would have the Galilean group instead of [the restricted Poincaré group]. Since Galilean boosts commute with spatial translations (time being absolute), the brackets between the corresponding generators vanish, hence no canonical commutation relations (CCR)! In the [c $\rightarrow \infty$ limit of the Poincaré algebra], *the CCR are a remnant of relativistic invariance where, due to the nonabsolute nature of simultaneity, spatial translations do not commute with pure Lorentz transformations*. [Italics in original].

Bohr & Ulfbeck also realized that the "Galilean transformation in the weakly relativistic regime[(46)]" is needed to construct a position operator for NRQM, and this

[112] As with RBW, detector clicks are not caused by impinging particles; in fact they're not caused by any*thing*, and NRQM simply provides the distributions of uncaused clicks. Since Bohr *et al.* do not further assume that the detector itself is a collection of fortuitous events, they seem to distinguish between a macroscopic, causal world and a microscopic fortuitous world.

transformation "includes the departure from simultaneity, which is part of relativistic invariance." Specifically, they note that the commutator between a "weakly relativistic" boost and a spatial translation results in "a time displacement," which is crucial to the relativity of simultaneity. Thus they write[47] ,

> "For ourselves, an important point that had for long been an obstacle, was the realization that the position of a particle, which is a basic element of nonrelativistic quantum mechanics, requires the link between space and time of relativistic invariance."

So, *the essence of non-relativistic quantum mechanics – its canonical commutation relations – is entailed by the relativity of simultaneity.*

To outline Kaiser's result, we take the limit c → ∞ in the following bracket of the Lie algebra of the Poincaré group:

$$[T_m, K_n] = \frac{-i}{c^2}\delta_{mn}T_0 \tag{1}$$

where subscripts m and n take values of 1, 2 and 3, T_0 is the generator of time translations, T_m are the generators of spatial translations, K_n are the boost generators, $i^2 = -1$, and c is the speed of light. We obtain

$$[T_m, K_n] = \frac{-i}{\hbar}\delta_{mn}M \tag{2}$$

where M is obtained from the mass-squared operator in the c → ∞ limit since

$$c^{-2}\hbar T_0 = c^{-2}P_0 \tag{3}$$

and

$$\frac{P_o}{c^2} = \left(M^2 + c^{-2}P^2\right)^{1/2} = M + \frac{P^2}{2Mc^2} + O(c^{-4}) \tag{4}.$$

Thus, $c^{-2}T_0 \rightarrow \frac{M}{\hbar}$ in the limit c → ∞. [M ≡ mI, where m is identified as "mass" by choice of 'scaling factor' ħ.] So, letting

$$P_m \equiv \hbar T_m \tag{5}$$

and

$$Q_n \equiv \frac{\hbar}{m} K_n \tag{6}$$

we have

$$[P_m, Q_n] = \frac{\hbar^2}{m}[T_m, K_n] = \left(\frac{-\hbar^2}{m}\right)\left(\frac{i}{\hbar}\right)\delta_{mn} mI = -i\hbar\delta_{mn} I \qquad (7).$$

Bohr & Ulfbeck point out that in this "weakly relativistic regime" the coordinate transformations now look like:

$$X = x - vt$$

$$T = t - \frac{vx}{c^2} \qquad (8).$$

These transformations differ from Lorentz transformations because they lack the factor

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-1/2} \tag{9}$$

which is responsible for time dilation and length contraction. And, these transformations differ from Galilean transformations by the temporal displacement

vx/c^2 which is responsible for the relativity of simultaneity, i.e., in a Galilean transformation time is absolute so T = t. Therefore, the spacetime structure of Kaiser *et al.* (K4) lies between Galilean spacetime (G4) and M4, and we see that the Heisenberg commutation relations are not the result of Galilean invariance, where spatial translations commute with boosts, but rather they result from the relativity of simultaneity per Lorentz invariance.

The received view has it that Schrödinger's equation is Galilean invariant, so it is generally understood that NRQM resides in G4 and therefore respects absolute simultaneity[(48)]. *Prima facie* the Kaiser *et al.* result seems incompatible with the received view, so to demonstrate that these results are indeed compatible, we now show that these results do not effect the Schrödinger dynamics[(49)]. To show this we simply operate on |ψ> first with the spatial translation operator then the boost operator and compare that outcome to the reverse order of operations. The spatial translation (by *a*) and boost (by v) operators in x are

$$U_T = e^{-iaT_x} \quad \text{and} \quad U_K = e^{-ivK_x} \tag{10}$$

respectively. These yield

$$U_K U_T |\psi\rangle = U_T U_K e^{-iavmI/\hbar} |\psi\rangle \tag{11}.$$

Thus, we see that the geometric structure of Eq. 7 introduces a mere phase to |ψ> and is therefore without consequence in the computation of expectation values. And in fact, this phase is consistent with that under which the Schrödinger equation is shown to be Galilean invariant[(50)].

Therefore, we realize that the spacetime structure for NRQM, while not M4 in that it lacks time dilation, length contraction and separability, nonetheless contains a "footprint of relativity[(51)]," i.e., the relativity of simultaneity. In light of this result, it should be clear that there is no metaphysical tension between SR and NRQM. This formal result gives us motivation for believing that NRQM is intimately connected to the geometry of spacetime consistent with the relativity of simultaneity and therefore we feel justified in couching an interpretation of NRQM in a blockworld, albeit a non-separable blockworld in which relations are fundamental to relata.

That relations are fundamental to trans-temporal objects, as opposed to the converse per a dynamic perspective, can be justified via the work of Bohr, Mottelson & Ulfbeck[(52)] who showed how the quantum density operator can be obtained via the symmetry group of the relevant observable. Their result follows from two theorems due to Georgi[(53)], i.e.,

> The matrix elements of the unitary, irreducible representations of G are a complete orthonormal set for the vector space of the regular representation, or alternatively, for functions of $g \in G$.

which gives[(54)]

> If a hermitian operator, H, commutes with all the elements, D(g), of a representation of the group G, then you can choose the eigenstates of H to transform according to irreducible representations of G. If an irreducible representation appears only once in the Hilbert space, every state in the irreducible representation is an eigenstate of H with the same eigenvalue.

What we mean by “the symmetry group” is precisely that group G with which some observable H commutes (although, these symmetry elements may be identified without actually constructing H). Thus, the mean value of our hermitian operator H can be calculated using the density matrix obtained wholly by D(g) and <D(g)> for all $g \in G$. Observables such as H are simply ‘along for the ride’ so to speak.

While we do not reproduce Bohr *et al.*’s derivation of the density matrix, we do provide a prefacing link with Georgi’s theorems. Starting with Eq. 1.68 of Georgi[(55)],

$$\sum_g \frac{n_a}{N}\left[D_a(g^{-1})\right]_{kj}\left[D_b(g)\right]_{lm} = \delta_{ab}\delta_{jl}\delta_{km} \qquad (12)$$

where n_a is the dimensionality of the irreducible representation, D_a, and N is the group order, and considering but one particular irreducible representation, D, we obtain the starting point (orthogonality relation) found in Bohr *et al.* (their Eq. 1),

$$\sum_g \frac{n}{N}\left[D(g^{-1})\right]_{kj}\left[D(g)\right]_{lm} = \delta_{jl}\delta_{km} \qquad (13)$$

where n is the dimension of the irreducible representation. From this, they obtain the density matrix as a function of the irreducible representations of the symmetry group elements, D(g), and their averages, <D(g)>, i.e., (their Eq. 6):

$$\rho \equiv \frac{n}{N}\sum_{g} D(g^{-1})\langle D(g)\rangle \qquad (14).$$

The methodological significance of the Bohr *et al.* result is that any NRQM system may be described with the appropriate *spacetime* symmetry group. The philosophical significance of this proof is more interesting, and one rooted in RBW's ontology of spacetime relationalism. This ontology, as we will argue in the following section, easily resolves the conceptual problems of NRQM while conveying an underlying unity between SR and NRQM.

Exactly what it means to say relations are fundamental to relata will be illustrated technically for NRQM by the example in section 4 in terms of the spacetime symmetries of the experimental configuration, and an even more fundamental conception of relationalism will be outlined via the proposed spatiotemporally discrete formalism in the remainder of this section, but we pause here to introduce the idea heuristically via a graphical representation of a non-separable blockworld. Figure 1 shows the links of a graph for two (implied) worldlines in a relational G4. The vertical links (temporal translations) are generated by the Hamiltonian and the horizontal links (spatial translations) are generated by the momentum. Since boosts commute with spatial translations, the boosted version looks the same, i.e., spatial hypersurfaces are the same for observers in relative motion. Therefore, the only way to move along worldline 1 or 2 is via vertical links, i.e., horizontal displacement between worldlines cannot result in any temporal displacement along the worldlines. This represents the temporal Galilean transformation, T = t, consistent with presentism. In a spacetime where boosts don't commute with spatial translations, the temporal coordinate transformation contains a translation, e.g., vx/c^2 in Eq. 8. A relational spacetime of this type is represented graphically in Figure 2. In this type of spacetime it is possible to move along worldline 1 or 2 temporally by moving between the worldlines using the boosted spatial hypersurfaces, thus the blockworld implication. If spatial distance is only defined via the horizontal links between worldlines, then we say the spacetime is *non-separable* as explained in section 1.4.

In an effort to formalize the idea that spatial separation exists only between interacting trans-temporal objects[(56)], we are exploring a spatiotemporally discrete formalism underlying quantum physics with NRQM following in the spatially discrete, temporally continuous limit and QFT following in the limit of both spatial and temporal continuity (Figure 3). This approach constitutes a *unification* of physics as opposed to a mere *discrete approximation* thereto, since we are proposing a source for the action, which is otherwise fundamental. So, for example, the spatiotemporally discrete counterpart to the QFT transition amplitude for interacting sources without scattering

$$Z = \int D\varphi \exp\left[i\int d^4x \left[\frac{1}{2}(d\varphi)^2 - V(\varphi) + J(x)\varphi(x) \right] \right] \quad (15)$$

is

$$Z = \int ... \int dQ_1 ... dQ_N \exp\left[\frac{i}{2} Q \cdot A \cdot Q + iJ \cdot Q \right] \quad (16)$$

when V(φ) is quadratic, e.g., harmonic oscillator per standard QFT. A_{ij} is the discrete matrix counterpart to the differential operator of Eq. (15) while J_m and Q_n are the discrete vector versions of *J(x)* and φ*(x)*. The discrete action, $\frac{1}{2} Q \cdot A \cdot Q + J \cdot Q$, is considered a functional, which we may write as $\frac{1}{2}|\alpha\rangle\langle\beta| + \langle J|$, of Q_n, which we may write as $\langle Q|$ or $|Q\rangle$. Regions in Q_n space where the action is stationary, i.e., invariant/symmetric, contribute most prominently to the transition amplitude[113]. Therefore, the functional is constructed so that what one means by trans-temporal objects, space and time, per $\langle J|$ and $|\alpha\rangle\langle\beta|$ respectively, are self-consistently defined

[113] Each possible experimental outcome of a given experiment requires its own "all at once" description yielding its own transition amplitude. For the case of spatially discrete sources, Z is the probability amplitude so it provides a frequency over the possible outcomes via the Born rule.

and harbor the desired fundamental symmetries (Figure 3). This is of course similar to the modus operandi of theoretical particle physics, the difference being the discrete formalism allows for (requires) the explicit construct of trans-temporal objects in concert with the spacetime metric whereas the spatiotemporally continuous starting point of QFT harbors tacit assumptions/constraints[114].

The solution to Eq. (16) is

$$Z = \left(\frac{(2i\pi)^N}{\det(A)} \right)^{1/2} \exp\left[-\frac{i}{2} J \cdot A^{-1} \cdot J \right] \tag{17}.$$

Since A_{ij} has an inverse, it has a non-zero determinant so it's composed of N linearly independent vectors in its N-dimensional, representational vector space. Thus, any vector in this space may be expanded in the set of vectors comprising A_{ij}. Specifically, the vector J_m, which will be used to represent 'sources' in the experimental set-up, can be expanded in the vectors of A_{ij}. In this sense it is clear how relations, represented by A_{ij}, can be fundamental to relata, represented by J_m. In the case of two coupled harmonic oscillators we have

$$V(q_1, q_2) = \sum_{a,b} \frac{1}{2} k_{ab} q_a q_b = \frac{1}{2} k q_1^2 + \frac{1}{2} k q_2^2 + k_{12} q_1 q_2$$

where $k_{11} = k_{22} = k$ and $k_{12} = k_{21}$, so our Lagrangian is

$$L = \frac{1}{2} m \dot{q}_1^2 + \frac{1}{2} m \dot{q}_2^2 - \frac{1}{2} k q_1^2 - \frac{1}{2} k q_2^2 - k_{12} q_1 q_2$$

and the spatially and temporally discrete version of A_{ij} in Eq. (16) would be

[114] That one must explicitly construct the trans-temporal objects, space and time of the discrete action suggests there may exist a level of formalism fundamental to the action. Toffoli[(57)] has proposed that a mathematical tautology resides at this most fundamental level, e.g., "the boundary of a boundary is zero" whence general relativity and electromagnetism[(58)]. Elsewhere, using discrete graph theory, we propose a self-consistency criterion which is also based on this tautology (quant-ph/07).

$$A = -\begin{pmatrix} \frac{m}{\Delta t} + k\Delta t & \frac{-2m}{\Delta t} & \frac{m}{\Delta t} & 0 & \ldots & 0 & k_{12}\Delta t & 0 & \\ 0 & \frac{m}{\Delta t} + k\Delta t & \frac{-2m}{\Delta t} & \frac{m}{\Delta t} & 0 & \ldots & 0 & k_{12}\Delta t & \\ & & & \ddots & & & & & \\ k_{12}\Delta t & 0 & \ldots & \frac{m}{\Delta t} + k\Delta t & \frac{-2m}{\Delta t} & \frac{m}{\Delta t} & 0 & \ldots & \\ 0 & k_{12}\Delta t & 0 & \ldots & \frac{m}{\Delta t} + k\Delta t & \frac{-2m}{\Delta t} & \frac{m}{\Delta t} & 0 & \\ & & & & \ddots & & & & \end{pmatrix} \quad (18).$$

The process of temporal identification $Q_n \rightarrow q_i(t)$ may be encoded in the blocks along the diagonal of A_{ij} whereby the spatial division between the $q_i(t)$ would then be encoded in the relevant off-diagonal (interaction) blocks:

$$A = \begin{pmatrix} \boxed{\begin{matrix} \ddots & & \\ & q_1(t) & \\ & & \ddots \end{matrix}} & q_1(t) \Leftrightarrow q_2(t) \\ q_2(t) \Leftrightarrow q_1(t) & \boxed{\begin{matrix} \ddots & & \\ & q_2(t) & \\ & & \ddots \end{matrix}} \end{pmatrix}.$$

The discrete formulation illustrates nicely how NRQM tacitly assumes an *a priori* process of trans-temporal identification, $Q_n \rightarrow q_i(t)$. Indeed, there is no principle which dictates the construct of trans-temporal objects fundamental to the formalism of dynamics in general – these objects are “put in by hand.” Thus, RBW suggests the need for a fundamental principle which would explicate the trans-temporal identity employed tacitly in NRQM, QFT and all dynamical theories. Since our starting point does not contain trans-temporal objects, space or time, we have to formalize counterparts to these concepts. Clearly, the process $Q_n \rightarrow q_i(t)$ is an organization of the set Q_n on two levels—there is the split of the set into subsets, one for each 'source', and there is the ordering over each subset. The split represents space (true multiplicity from apparent identity), the ordering represents time (apparent identity from true multiplicity)[115] and the result is objecthood (via relations). Again, the three concepts are inextricably linked in our formalism, thus our suggestion that they be related via a self-consistency criterion

(Figure 3).

In the limit of temporal continuity, Eq. (18) dictates we find the inverse of

$$-\begin{pmatrix} m\frac{d^2}{dt^2}+k & k_{12} \\ k_{12} & m\frac{d^2}{dt^2}+k \end{pmatrix}$$

to obtain Eq. (17) so that

$$-\frac{1}{2}Q\cdot A\cdot Q \rightarrow \int\left(\frac{m}{2}q_1\ddot{q}_1+\frac{1}{2}kq_1^2+\frac{m}{2}q_2\ddot{q}_2+\frac{1}{2}kq_2^2+k_{12}q_1q_2\right)dt$$

in our NRQM action. Solving

$$-\begin{pmatrix} m\frac{d^2}{dt^2}+k & k_{12} \\ k_{12} & m\frac{d^2}{dt^2}+k \end{pmatrix}D_{im}(t-t')=\begin{pmatrix} \delta(t-t') & 0 \\ 0 & \delta(t-t') \end{pmatrix}$$

for $D_{im}(t-t')$ we find

[115] These definitions of space and time follow from a fundamental principle of standard set theory, *multiplicity iff discernibility* (W.M. Stuckey, *Phys. Ess.* **12**, 414-419, (1999)).

$$D_{im}(t-t') = -\begin{pmatrix} \int \frac{d\omega}{2\pi} A(\omega) e^{i\omega(t-t')} & \int \frac{d\omega}{2\pi} B(\omega) e^{i\omega(t-t')} \\ \int \frac{d\omega}{2\pi} B(\omega) e^{i\omega(t-t')} & \int \frac{d\omega}{2\pi} A(\omega) e^{i\omega(t-t')} \end{pmatrix}$$

with

$$A = \frac{\omega^2 m - k}{k_{12}^2 - \left(\omega^2 m - k\right)^2} \qquad \text{and} \qquad B = \frac{k_{12}}{k_{12}^2 - \left(\omega^2 m - k\right)^2}.$$

The NRQM amplitude in this simple case is then given by

$$Z(J) \propto \exp\left[-\frac{i}{\hbar}\iint dt dt' J_1(t) D_{12} J_2(t')\right] = \exp\left[\frac{i}{\hbar}\iiint \frac{dt' dt d\omega}{2\pi} \frac{J_1(t) k_{12} e^{i\omega(t-t')} J_2(t')}{k_{12}^2 - (\omega^2 m - k)^2}\right]$$

having restored $\hbar$, used $D_{12} = D_{21}$ and ignored the "self-interaction" terms $J_1 D_{11} J_1$ and $J_2 D_{22} J_2$. Fourier transforms give

$$Z(j) \propto \exp\left[\frac{i}{\hbar}\int \frac{d\omega}{2\pi} \frac{j_1(\omega)^* k_{12} j_2(\omega)}{\left(k_{12}^2 - (\omega^2 m - k)^2\right)}\right] \tag{19}$$

with J_1(t) real.

If we now use this amplitude to analyze the twin-slit experiment, we can compare the result to that of Schödinger wave mechanics and infer the non-separability of spatial distance therein. There are four J's which must be taken into account when computing the amplitude (figure 4), so we will use Eq. (19) to link J_1 with each of J_2 and J_4, and J_3 with each of J_2 and J_4, i.e., $J_1 \leftrightarrow J_2 \leftrightarrow J_3$ and $J_1 \leftrightarrow J_4 \leftrightarrow J_3$. In doing so, we ignore the contributions from other pairings, i.e., the exact solution would contain one integrand with $Q_n \rightarrow q_i(t)$, i = 1,2,3,4. Finally, we assume a monochromatic source of the form $j_1(\omega)^* = \Gamma_1\delta(\omega-\omega_o)$ with Γ_1 a constant, so the amplitude between J_1 and J_2 is

$$Z(j) \propto \exp\left[\frac{i}{2\pi\hbar}\frac{\Gamma_1 k_{12}\, j_2(\omega_o)}{\left(k_{12}^2-(\omega_o^2 m-k)^2\right)}\right]$$

whence we have for the amplitude between J_1 and J_3 via J_2 and J_4

$$\psi \propto \exp\left[\frac{i}{2\pi\hbar}(\Gamma_1 d_{12}\, j_2+\Gamma_2 d_{23}\, j_3)\right]+\exp\left[\frac{i}{2\pi\hbar}(\Gamma_1 d_{14}\, j_4+\Gamma_4 d_{43}\, j_3)\right] \qquad (20)$$

where

$$d_{im}=\frac{k_{im}}{\left(k_{im}^2-(\omega_o^2 m-k)^2\right)} \qquad (21)$$

with ψ the NRQM amplitude. [Z corresponds to the NRQM propagator which yields the functional form of ψ between spatially localized sources, as will be seen below.] With the source equidistance from either slit (or, equivalently, with slits replaced by a pair of coherent laser-excited atoms) the phase $\Gamma_1\, d_{12}j_2$ equals the phase $\Gamma_1\, d_{14}j_4$, so we have the familiar form

$$\psi \propto \exp\left[\frac{i}{2\pi\hbar}(\Gamma_2 d_{23}\, j_3)\right]+\exp\left[\frac{i}{2\pi\hbar}(\Gamma_4 d_{43}\, j_3)\right] \qquad (22).$$

Now we need the corresponding result from Schödinger wave mechanics with free-particle propagator[59]

$$U(x_2,t;x_1,0)=\sqrt{\frac{m}{2\pi\hbar i t}}\exp\left[\frac{im(x_2-x_1)^2}{2\hbar t}\right]$$

for a particle of mass m moving from x_1 to x_2 in time t. This ‘exchange’ particle has no dynamic counterpart in the formalism used to obtain Eq. (22), but rather is associated with the oscillatory nature of the spatially discrete ‘source’ (see below). According to our view, this propagator is tacitly imbued “by hand” with notions of trans-temporal objects, space and time per its derivation via the free-particle Lagrangian. In short, the construct of this propagator bypasses explicit, self-consistent construct of trans-temporal objects, space and time thereby ignoring the self-consistency criterion fundamental to the action. The self-inconsistent, tacit assumption of a single particle with two worldlines (a "free-particle propagator" for each slit) is precisely what leads to the "mystery" of the twin-slit experiment[116]. This is avoided in our formalism because *Z* does not represent the propagation of a particle between 'sources', e.g., $q_i(t) \neq x(t)$ as explained *supra*. Formally, the inconsistent, tacit assumption is reflected in $-\frac{1}{2}Q \cdot A \cdot Q \rightarrow \int\left(\frac{m}{2}\dot{x}^2\right)dt$ where ontologically *m* (which is *not* the same *m* that appears in our oscillator potential) is the mass of the 'exchange' particle (i.e., purported dynamical/diachronic entity moving between 'sources' – again, the ontic status of this entity is responsible for the "mystery") and $x(t)$ (which, again, is *not* equal to $q_i(t)$) is obtained by *assuming* a particular spatial metric (this assumption *per se* is not responsible for the "mystery"). Its success in producing an acceptable amplitude when integrating over all paths $x(t)$ in space ('wrong' techniques can produce 'right' answers), serves to deepen the "mystery" because the formalism, which requires interference between different spatial paths, is not consistent with its antecedent ontological assumption, i.e., single particle causing a single click. There is no such self-inconsistency in our approach, because *Z* is not a "particle propagator" but a 'mathematical machine' which measures the degree of symmetry contained in the "all at once" configuration of trans-temporal objects, space and time represented by *A* and *J*, as explained *supra*. Thus, this NRQM "mystery" results from an attempt to tell a dynamical story in an adynamical situation. Continuing, we have

$$\psi(x_2,t) = \int U(x_2,t;x',0)\psi(x',0)dx'$$

[116] Per Feynman, the twin-slit experiment "has in it the heart of quantum mechanics. In reality, it contains the *only* mystery" (R.P. Feynman, R.B. Leighton & M. Sands, *The Feynman Lectures on Physics*,
Vol. III, Quantum Mechanics (Addison-Wesley, Reading, 1965), p. 1-1).

and we want the amplitude between sources located at x_1 and x_2, so $\psi(x',0) = \alpha\delta(x' - x_1)$ whence

$$\psi_{12} = \alpha\sqrt{\frac{m}{2\pi\hbar it}}\exp\left[\frac{imx_{12}^2}{2\hbar t}\right] = \alpha\sqrt{\frac{m}{2\pi\hbar it}}\exp\left[\frac{ipx_{12}}{2\hbar}\right]$$

where x_{12} is the spatial distance between sources J_1 and J_2, t is the interaction time and $p = \frac{mx_{12}}{t}$. Assuming the interaction time is large compared to the 'exchange' particle's characteristic time so that x_{12} is large compared to $\frac{\hbar}{p}$ we have

$$\psi = \psi_{23} + \psi_{43} \propto \exp\left[\frac{ipx_{23}}{2\hbar}\right] + \exp\left[\frac{ipx_{43}}{2\hbar}\right] \tag{23}$$

as the Schödinger dynamical counterpart to Eq. (22), whence we infer

$$\frac{p}{2\hbar}x_{ik} = \frac{\Gamma_i d_{ik} j_k}{2\pi\hbar}\,. \tag{24}$$

Assuming the impulse j_k is proportional to the momentum transfer p, we have

$$x_{im} \propto \frac{\Gamma_i k_{im}}{\left(k_{im}^2 - (\omega_o^2 m - k)^2\right)} \tag{25}$$

relating the spatial separation x_{im} of the trans-temporal objects J_i and J_m to their intrinsic (m, k, ω_o) and relational (k_{im}) 'dynamical' characteristics.

As we stated in section 1, the metric of Eq. (25) provides spatial distance only between interacting ($k_{im} \neq 0$) trans-temporal objects, in stark contrast to the metric field of relativity theory which takes on values at each point of the differentiable spacetime manifold, even in regions where the stress-energy tensor is zero. And, as is clear from our presentation, there is no 'exchange' particle or wave (of momentum p

or otherwise) moving ‘through space’ from the source to the detector to ‘cause’ a detection event. Thus, we have a formal counterpart to our heuristic graphical illustration whereby there is no concept of spatial distance in spacetime regions where the stress-energy tensor vanishes.

3. RESOLVING THE CONCEPTUAL PROBLEMS OF NRQM

Before we use RBW to address the conceptual problems of NRQM, we pause to enumerate the RBW ontology and methodology.

1. We may view each piece of equipment in an experimental set-up as resulting from a large number of spatiotemporally dense relations, so low-intensity sources and high-sensitivity detectors must be used to probe the rarified realm of NRQM (Figure 3).

2. A “detector click” or “detector event” is a subset of the detector that also results from a large number of spatiotemporally dense relations; we infer the existence of a rarified set of relations between the source and the detector at the beginning of the click’s worldline.

3. It is this inferred, rarified set of relations for which we compute the transition amplitude.

4. A transition amplitude must be computed for each of all possible click locations (experimental outcomes) and this calculation must include (tacitly if not explicitly) all relevant information concerning the spacetime relationships (e.g., distances and angles) and property-

defining relations (e.g., degree of reflectivity) for the experimental equipment.

5. The relative probability of any particular experimental outcome can then be determined via the transition amplitude, which is the probability amplitude of NRQM for spatially discrete sources.

3.1 The Measurement Problem. According to the account developed here, we offer a deflation of the measurement problem with a novel form of a "statistical interpretation." The fundamental difference between our version of this view and the usual understanding of it is the following: whereas on the usual view the state description refers to an "ensemble" which is an ideal collection of similarly prepared quantum particles, "ensemble" according to our view is just an ideal collection of spacetime regions S_i "prepared" with the same spatiotemporal boundary conditions per the experimental configuration itself. The union of the click events in each S_i, as $i \to \infty$, produces the characteristic Born distribution. Accordingly, probability in RBW is interpreted per relative frequencies.

On our view, the wavefunction description of a quantum system can be interpreted statistically because we now understand that, as far as measurement outcomes are concerned, the Born distribution has a basis in the spacetime symmetries of the experimental configuration. Each "click," which some would say corresponds to the impingement of a particle onto a measurement device with probability computed from the wavefunction, corresponds to spacetime relations in the context of the experimental configuration. The measurement problem *exploits* the possibility of extending the wavefunction description from the quantum system to the whole measurement apparatus, whereas the "all at once" description according to RBW *already includes* the apparatus via the spacetime symmetries instantiated by the *entire* experimental configuration. The measurement problem is therefore a non-starter on our view.

Since a trans-temporal object (such as a detector) possesses properties (to include click distributions) according to a spatiotemporally global set of relations (all trans-temporal objects are defined non-separably in "a vast spatiotemporal mosaic"), one could think of RBW as a local hidden-variable theory (such as BCQM) whereby the relations or symmetries provide the "hidden variables." One can construct a *local* hidden-variable theory if one is willing to claim that systems which presumably have not interacted may nevertheless be correlated. Such correlations appear to require some kind of universal conspiracy behind the observed phenomena, hence Peter Lewis(60) calls such theories "*conspiracy theories.*" As he says, "the obvious strategy is the one that gives conspiracy theories their name; it involves postulating a vast, hidden mechanism whereby systems that apparently have no common past may nevertheless have interacted." Independence is the assumption that the hidden variables assigned to the particles are independent of the settings of the measuring devices. If Independence is violated, then a local hidden-variable theory (a conspiracy theory) can in principle account for the Bell correlations. But how *could* Independence be violated? The common cause principle tells us that every systematic correlation between events is due to a cause that they share. As a trivial consequence, systems that have not interacted cannot be systematically correlated, and all appearances indicate that the particles and the measuring devices in EPR-Bell phenomena do not interact before the measurement. Lewis(61) suggests three possibilities for violating Independence:

> Hidden-mechanism theories and backwards-causal theories are both strategies for constructing a local hidden-variable theory by violating Independence. The first of these postulates a mechanism that provides a cause in the past to explain the Bell correlations, and the second postulates a cause in the future. But there is a third strategy that is worth exploring here, namely that the common cause principle is *false*—that some correlations simply require no causal explanation.

Lewis calls the third strategy of denying the common cause principle "acausal conspiracy theories;" RBW can be reasonably characterized in this fashion with the spacetime symmetries playing the role of the hidden-variables. However such a characterization is also misleading in that we are not supplementing NRQM in any standard sense, such as modal interpretations *a la* Bohm. We are not claiming that quantum mechanics is incomplete but that the spacetime symmetries and K4 provide a deeper explanation than NRQM as standardly and *dynamically* conceived. At least at this level, there is no deeper explanation for individual outcomes of quantum experiments than that provided by the structure of K4 and the spacetime symmetries underlying each experimental configuration[117]. The measurement problem arises because of the assumption that the *dynamics* are the deepest part of the explanatory story, the very heart of quantum mechanics, an assumption RBW rejects. In short, RBW provides a *kinematic* (pre-dynamical) solution to the measurement problem.

3.2 Entanglement and Non-locality. The blockworld description of an experiment includes its outcomes, and it is possible that outcomes are correlated via symmetries included in the definition of the experiment per the action. Again, the description is "all at once" to include outcomes so if these outcomes are correlated per the action, which was constructed to represent a specific subset of reality instantiated (approximately) by the experiment in question, then there is no reason to expect entanglement will respect any kind of common cause principle. As we stated supra, causality/dynamism are not essential in the algorithm for constructing a blockworld description. Although RBW is *fundamentally* adynamical (relata from relations "all at once," rather than relata from relata in a causal or dynamical structure), it does not harbor non-locality in the odious sense of "spooky action at a distance" as in Bohm for example, i.e., there are no space-like worldlines (implied or otherwise) between space-like separated, correlated outcomes. Again, this is where RBW suggests a new approach to fundamental physics because dynamical entities are modeled fundamentally via relations in "a vast spatiotemporal mosaic" instead of via "interacting" dynamical constituents *a la* particle physics[118].

Our account provides a clear description, in terms of relations in a blockworld, of quantum phenomena *that does not suggest the need for a "deeper" causal or dynamical explanation*. If explanation is simply determination, then our

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[117] Of course, RBW implies a formalism fundamental to NRQM as shown in section 2. This implication sets RBW apart from mere interpretations of NRQM.

[118] This means particles physics per QFT is displaced from its fundamental status (Figure 3). The current hierarchy has QFT at the bottom (fundamental) leading to NRQM in the limit of (0+1) spacetime dimensions and leading to classical physics in the limit of $\hbar \rightarrow 0$. The completion of physics per this scheme requires a quantum version of GR, i.e., quantum gravity.

view explains the structure of quantum correlations by invoking what can be called *acausal, adynamical global determination relations*. In NRQM, these "all at once" determination relations are given by the spacetime symmetries which underlie a particular experimental set-up. Not objects governed by dynamical laws, but rather acausal relations per the relevant spacetime symmetries do the fundamental explanatory work according to RBW. We can invoke the *entire* spacetime configuration of the experiment so as to predict, and explain, the EPR-Bell correlations. This then is a geometrical, acausal and adynamical account of entanglement.

In summary, the spacetime symmetries of an NRQM experiment can be used to construct its quantum density operator, such a spacetime (K4) is one for which simultaneity is relative, and events in the detector region(s) evidence rarified relations between spatially discrete sources, which are trans-temporal objects and thus modeled as temporally continuous (recall from section 2 that NRQM obtains in the temporally continuous, spatially discrete limit of the discrete action). To evidence the explanatory power of this interpretation, we use it to resolve a particularly challenging conundrum in NRQM.

4. RESOLVING THE QUANTUM LIAR PARADOX

We now apply the Bohr *et al.* method to a particular experimental set-up. In two recent articles, Elitzur and Dolev try to establish something like the negation of the blockworld view, by arguing for an intrinsic direction of time given by the dynamical laws of quantum theory[(62)]. They put forward the strong claim that certain experimental set-ups such as the quantum liar experiment (QLE) "entail inconsistent histories" that "undermine the notion of a fixed spacetime within which all events maintain simple causal relations. Rather, it seems that quantum measurement can sometimes 'rewrite' a process's history[(63)]." In response, they propose a "spacetime dynamics theory[(64)]." Certainly, if something like this is true, then blockworld is jeopardized. By applying the geometrical interpretation of quantum mechanics to the "quantum liar" case, we will not only show that the blockworld assumption is consistent with such experiments, but that blockworld *a la* our geometric interpretation provides a non-trivial and unique explanation of such experiments.

4.1 Mach-Zehnder Interferometer & Interaction-Free Measurements. Since QLE employs interaction-free measurement[(65)] (IFM), we begin with an explication of IFM. Our treatment of IFM involves a simple Mach-Zehnder interferometer (MZI, Figure 5;

BS = beam splitter, M = mirror and D = detector). All photons in this configuration are detected at D1 since the path to D2 is ruled out by destructive interference. This obtains even if the MZI never contains more than one photon in which case each photon "interferes with itself." If we add a detector D3 along either path (Figures 6a and 6b), we can obtain clicks in D2 since the destructive interference between BS2 and D2 has been destroyed by D3. If we introduce detectors along the upper and lower paths between the mirrors and BS2, obviously we do not obtain any detection events at D1 or D2.

To use this MZI for IFM we place an atom with spin X+, say, into one of two boxes according to a Z spin measurement, i.e., finding the atom in the Z+ (or Z-) box means a Z measurement has produced a Z+ (or Z-) result. The boxes are opaque for the atom but transparent for photons in our MZI. Now we place the two boxes in our MZI so that the Z+ box resides in the lower arm of the MZI (Figure 7). If we obtain a click at D2, we know that the lower arm of the MZI was blocked as in Figure 6a, so the atom resides in the Z+ box. However, the photon must have taken the upper path in order to reach D2, so we have measured the Z component of the atom's spin without an interaction. Accordingly, the atom is in the Z+ spin state and subsequent measurements of X spin will yield X+ with a probability of one-half (whereas, we started with a probability of X+ being unity).

4.2 Quantum Liar Experiment. QLE leads to the "quantum liar paradox" of Elitzur & Dolev[(66)] because it presumably instantiates a situation isomorphic to a liar paradox such as the statement: "this sentence has never been written." As Elitzur & Dolev put it, the situation is one in which we have two distinct non-interacting atoms in different wings of the experiment that could only be entangled via the mutual interaction of a single photon. However one atom is found to have blocked the photon's path and thus it could not interact with the other atom via the photon and the other atom should therefore not be entangled with the atom that blocked the photon's path. But, by violating Bell's inequality, its "having blocked the photon" was affected by the measurement of the other atom, hence the paradox. Our explication of the paradox differs slightly in that we describe outcomes via spin measurements explicitly.

We start by exploiting IFM to entangle two atoms in an EPR state, even though the two atoms never interact with each other or the photon responsible for their entanglement(67) [119]. We simply add another atom prepared as the first in boxes Z2+/Z2- and position these boxes so that the Z2- box resides in the upper arm of the MZI

(Figure 8). Of course if the atoms are in the Z1+/Z2- states, we have blocked both arms and obtain no clicks in D1 or D2. If the atoms are in Z1-/Z2+ states, we have blocked neither arm and we have an analog to Figure 5 with all clicks in D1. We are not interested in these situations, but rather the situations of Z1+ *or* Z2- as evidenced by a D2 click. Thus, a D2 click entangles the atoms in the EPR state:

$$\frac{1}{\sqrt{2}}\left(|Z+\rangle_1|Z+\rangle_2+|Z-\rangle_1|Z-\rangle_2\right) \tag{26}$$

and subsequent spin measurements with orientation of the Stern-Gerlach magnets in $\Re^2$ as shown in Figure 9 will produce correlated results which violate Bell's inequality precisely as illustrated by Mermin's apparatus(69). This EPR state can also be obtained using *distinct* sources(70) (Figure 10), so a single source is not necessary to entangle the atoms. In either case, subsequent spin measurements on the entangled atoms will produce violations of Bell's inequality.

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[119] The non-interaction of the photons and atoms is even more strongly suggested in an analogous experiment, where a super-sensitive bomb is placed in on of the arms of the MZI(68).

Suppose we subject the atoms to spin measurements after all D2 clicks and check for correlations thereafter. A D2 click means that one (and only one) of the boxes in an arm of the MZI is acting as a "silent" detector, which establishes a "fact of the matter" as to its Z spin and, therefore, the other atom's Z spin. In all trials for which we chose to measure the Z spin of both atoms this fact is confirmed. But, when we amass the results from all trials (to include those in which we measured Γ and/or Δ spins) and check for correlations we find that Bell's inequality is violated, which indicates the Z component of spin *cannot* be inferred as "a matter of unknown fact" in trials prior to Γ and/or Δ measurements. This is not consistent with the apparent "matter of fact" that a "silent" detector must have existed in one of the MZI arms in order to obtain a D2 click, which entangled the atoms in the first place. To put the point more acutely, Elitzur and Dolev(71) conclude their exposition of the paradox with the observation that

> *The very fact that one atom is positioned in a place that seems to preclude its interaction with the other atom leads to its being affected by that other atom.* This is logically equivalent to the statement: "This sentence has never been written.[120]"

In other words, *there must be a fact of the matter concerning the Z spins in order to produce a state in which certain measurements imply there was no fact of the matter for the Z spins.*

4.3 Geometrical Account of QLE. By limiting any account of QLE to a story about the interactions of objects or entities in spacetime (such as the intersection of point-particle-worldlines, or an everywhere-continuous process *connecting* two or more worldlines), it is on the face of it difficult to account for "interaction-free" measurements (since, naively, a necessary condition for an "interaction" is the "intersection of two or more worldlines"). Since the IFM in this experiment "generated" the entanglement, we can invoke the *entire* spacetime configuration of the experiment so as to predict, and explain, the EPR-Bell correlations in QLE.

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[120] This quote has been slightly modified per correspondence with the authors to correct a publisher's typo. In the original document they go on to point out that "[we] are unaware of any other quantum mechanical experiment that demonstrates such inconsistency."

Accordingly, spatiotemporal relations provide the ontological basis for our geometric interpretation of quantum theory, and on that basis, explanation (*qua* determination) of quantum phenomena can be offered. According to our ontology of relations, the distribution of clicks at the detectors reflects the spatiotemporal relationships between the source, beam splitters, mirrors, and detectors as described by the spacetime symmetry group – spatial translations and reflections in this case. The relevant 2D irreducible representations (irreps) for 1-dimensional translations and reflections are[72]

$$T(a) = \begin{pmatrix} e^{-ika} & 0 \\ 0 & e^{ika} \end{pmatrix} \quad \text{and} \quad S(a) = \begin{pmatrix} 0 & e^{-2ika} \\ e^{2ika} & 0 \end{pmatrix} \tag{27}$$

respectively, in the eigenbasis of T. *These are the fundamental elements of our geometric description of the MZI.* Since, with this ontology of spatiotemporal relations, the matter-geometry dualism has been collapsed, both "object" and "influence" reduce to *spacetime relations*. We can then obtain the *density matrix* for such a system via its spacetime symmetry group per Bohr *et al.* The "entanglement" is understood as correlated outcomes in an "all at once" description of the experiment per the symmetries of the action.

Consider now Figure 5, with the RBW interpretation of quantum mechanics in mind. We must now re-characterize that experimental set-up in our new geometrical language, using the formalism of Bohr *et al.* Let a detection at D1 correspond to the eigenvector |1> of *T*(*a*) (associated with eigenvalue e^{-ika}) and a detection at D2 correspond to the eigenvector |2> of *T*(*a*) (associated with eigenvalue e^{ika}). The source-detector combo alone is simply described by the click distribution |1>. The effect of introducing BS1 is to change the click distribution per the unitary operator

$$Q(a_o) \equiv \frac{1}{\sqrt{2}}\left(I - iS(a_o)\right) \tag{28}$$

where $a_o \equiv \pi/(4k)$. Specifically,

$$Q(a_o) = \frac{1}{\sqrt{2}}\left[\begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} - i\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\right] = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix} \tag{29}$$

and

$$|\psi\rangle = Q(a_o)|1\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & -1 \\ 1 & 1 \end{pmatrix}\begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 \\ 1 \end{pmatrix} \quad (30).$$

This is an eigenstate of the reflection operator, so introducing the mirrors does not change the click distribution. Introduction of the second beam splitter, BS2, changes the distribution of clicks at D1 and D2 per

$$|\psi_{final}\rangle = Q^{+}(a_o)|\psi\rangle = \frac{1}{\sqrt{2}}\begin{pmatrix} 1 & 1 \\ -1 & 1 \end{pmatrix}\begin{pmatrix} \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \quad (31).$$

Note there is no mention of photon interference here. We are simply describing the distribution of events (clicks) in spacetime (spatial projection, rest frame of MZI) using the fundamental ingredients in this type of explanation, i.e., spacetime symmetries (spatial translations and reflections in the MZI, rotations in the case of spin measurements). What it means to "explain" a phenomenon in this context is to provide the distribution of spacetime events per the spacetime symmetries relevant to the experimental configuration.

To complete our geometrical explanation of QLE we simply introduce another detector (D3 as in Figure 6a, say), which changes the MZI description *supra* prior to BS2 in that the distribution of clicks for the configuration is given by

$$|\psi_{final}\rangle = \begin{pmatrix} Q^{+}(a_o) & & 0 \\ & \ddots & 0 \\ 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} 1/\sqrt{2} \\ 0 \\ 1/\sqrt{2} \end{pmatrix} = \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 0 \\ -1/\sqrt{2} & 1/\sqrt{2} & 0 \\ 0 & 0 & 1 \end{pmatrix}\begin{pmatrix} 1/\sqrt{2} \\ 0 \\ 1/\sqrt{2} \end{pmatrix} = \begin{pmatrix} 1/2 \\ -1/2 \\ 1/\sqrt{2} \end{pmatrix} \quad (32).$$

Again, we need nothing more than Q^+, which is a function of the reflection symmetry operator, $S(a)$, to construct this distribution. And for the distribution of clicks for the configuration in Figure 6b

$$\left|\psi_{final}\right\rangle = \begin{pmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 0 \\ -1/\sqrt{2} & 1/\sqrt{2} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 0 \\ 1/\sqrt{2} \\ 1/\sqrt{2} \end{pmatrix} = \begin{pmatrix} 1/2 \\ 1/2 \\ 1/\sqrt{2} \end{pmatrix} \qquad (33).$$

Of course, spin measurements using the MZI boxes ("spin measurements on the atoms") are viewed as binary outcomes in space (spin ½) with respect to the orientation of the magnetic poles in a Stern-Gerlach device (SG). This is "how the atom was placed in the boxes according to spin." Successive spin measurements are described via rotation, i.e.,

$$\left|\psi_2\right\rangle = \begin{pmatrix} \cos\left(\frac{\theta}{2}\right) & -\sin\left(\frac{\theta}{2}\right) \\ \sin\left(\frac{\theta}{2}\right) & \cos\left(\frac{\theta}{2}\right) \end{pmatrix} \left|\psi_1\right\rangle$$

where $|\psi_1\rangle$ is created by a source, magnet and detector and $|\psi_2\rangle$ obtains when introducing a second SG measurement at an angle θ with respect to the first. The three possible orientations for SG measurments in $\Re^2$ considered here and in the Mermin apparatus (initial X+ orientation aside) are shown in Figure 9. As with MZI outcomes, the description of spin measurement is to be understood via the spatiotemporal relationships between source(s) and detector(s) per the experimental arrangement, i.e., there are no "atoms impinging on the detectors" behind the SG magnets per their spins. There are just sources, detectors and magnets whose relative orientations in space provide the computation of probabilities for event (click) distributions.

This constitutes an acausal and *adynamical* characterization and explanation of entanglement. According to our view, the *structure of correlations* evidenced by QLE is *determined by* the spacetime relations instantiated by the experiment, understood as a spatiotemporal whole (blockworld). This determination is obtained by *describing* the experimental arrangement from beginning to end (including outcomes) via an action which contains the spatiotemporal symmetry structure relevant to the experimental arrangement and is constructed from self-consistently defined trans-temporal objects, space and time. Since

(i) the explanation lies in the spacetime relations evidenced by (inferred from) detector events,

(ii) the distribution of detector events follows from an "all at once" description of the experimental set-up via its spatially discrete action,

(iii) the action is obtained by a self-consistent definition of trans-temporal objects, space and time,

(iv) the self-consistent construct of the action instantiates the relevant, fundamental symmetries characterizing the experiment and

(v) the ontological structural realism of RBW collapses the matter-geometry dualism,

our geometrical quantum mechanics provides for an *acausal*, *global* and *adynamical* understanding of NRQM phenomena.

4.4 QLE and Blockworld. Our analysis of QLE shows the explanatory necessity of the reality of all events—in this case the reality of all phases (past, present and future) of the QLE experiment. We can provide an illustrative, though qualitative, summary by dividing the QLE into three spatiotemporal phases, as depicted in Figures 11 – 13. In the first phase the boxes Z1+, Z1-, Z2+, and Z2- are prepared – without such preparation the MZI is unaffected by their presence. In a sense, the boxes are being prepared as detectors since they have the potential to respond to the source ("atom absorbs the photon" in the language of dynamism). The second phase is to place the four boxes in the MZI per Figure 8 and obtain a D1 or D2 click (null results are discarded). The third phase is to remove the four boxes and do spin measurements. The entire process is repeated many times with all possible Γ, Δ and Z spin measurements conducted randomly in phase 3. As a result, we note that correlations in the spin outcomes after D2 clicks violate Bell's inequality.

We are not describing "photons" moving through the MZI or "atoms" whose spin-states are being measured. According to our ontology, clicks are evidence not of an impinging particle-in-motion, but of rarified *spacetime relations* which are a subset of the dense set comprising the equipment of the experiment. If a Z measurement is made on either pair of boxes in phase 3, an inference can be made *a posteriori* as to which box acted as a "silent" detector in phase 2. If Γ and/or Δ measurements are done on each pair (Figure 11), then there is *no fact of the matter* concerning the detector status of the original boxes (boxes had to be recombined to make Γ and/or Δ measurements). This is not simply a function of ignorance because if it was possible to identify the "silent" detectors before the Γ and/or Δ measurements were made, the Bell assumptions would be met and the resulting spin measurements would satisfy the Bell inequality. Therefore, *that none of the four boxes can be identified as a detector in phase 2 without a Z measurement in phase 3 is an ontological, not epistemological, fact* and points to the necessity of an "all at once" explanation.

Notice that what obtains in phase 3 "determines" what obtains in phase 2, so we have a true "delayed-choice" experiment. For example, suppose box Z2- is probed in
phase 3 (Z measurement) and an event is registered (an "atom resides therein," Figure 12). Then, the Z2- and Z1- boxes are understood during phase 3 to be detectors in phase 2. However, nothing in the blockworld has "changed" – the beings in phase 2 have not "become aware" of which boxes are detectors. Neither has anything about

the boxes in phase 2 "changed." According to our view, the various possible spatiotemporal distributions of events are each determined by NRQM *as a whole throughout space and time.*

To further illustrate the blockworld nature of the correlations, suppose we make spin measurements after a D1 click. Figure 13 shows a spatiotemporal configuration of facts in phases 1, 2 and 3 consistent with a D1 click:

Phase 1: No prep

Phase 2: Boxes are not detectors, D1 click

Phase 3: Γ2 measurement, Δ1 measurement, No outcomes.

One can find correlated spatiotemporal facts by starting in any of the three phases:

Starting with phase 3, "No outcomes" → "No prep" in phase 1 and "Boxes are not detectors" and "D1 click" in phase 2. If you insisted on talking dynamically, you could say that the "No outcomes" result of phase 3 *determined* the "Boxes are not detectors" result of phase 2.

Starting with phase 2, "Boxes are not detectors" → "D1 click" in phase 2, "No prep" in phase 1 and "No outcomes" in phase 3.

Starting with phase 1, "No prep" → "No outcomes" in phase 3 and "Boxes are not detectors" and "D1 click" in phase 2.

One can chart implications from phase 1 to phase 3 then back to phase 2, since the order in which we chart implications in a spacetime diagram is meaningless (meta-temporal) to the blockworld inhabitants. In point of fact the collective characteristics in all three phases of QLE are acausally and globally (without attention to any common cause principle) determined by the spacetime symmetries of the experimental set-up; hence, the explanatory necessity of the blockworld. What *determines* the outcomes in QLE is not given in terms of influences or causes. In this way we resolve the quantum liar paradox with RBW by showing how "the paradox" is not only *consistent* with a blockworld structure, but actually strongly suggests an adynamical approach such as ours over interpretations involving dynamical entities and their histories. It is the *spatiotemporal configuration of QLE as a spacetime whole and its spacetime symmetries* that determine the outcomes and not *constructive (*a la *Einstein) entities with dynamical histories*.

5. CONCLUSION

According to our Relational Blockworld interpretation of non-relativistic quantum mechanics, one can do justice to the non-commutative structure of NRQM without being a realist about Hilbert space. The trick is to understand that the spacetime of NRQM is a non-separable, relational blockworld that respects locality per SR. Accordingly, one should not think of this spacetime as an empty vessel waiting to be imbued with worldlines and stress-energy because, per the fundamental self-consistency criterion, the concepts of time and space only have meaning in the context of trans-temporal objects, and vice-versa. While clicks in detectors are perfectly classical events, the clicks are not evidence of *constructive* quantum entities such as particles with worldlines. Rather, the clicks are manifestations of the relations composing elements of the experimental configuration as illustrated, for example, by the way RBW parses the quantum liar experiment via the irreps of spatial translations and reflections. This spacetime respects relativistic locality in that there are no faster-than-light “influences” or “productive” causes between space-like separated events, but it does harbor “all at once” geometric “correlations” outside the lightcone as determined acausally, adynamically and globally by the spacetime symmetries. Once again, such acausal and adynamical global determination relations do not respect any common cause principle. This fact should not bother anyone who has truly transcended the idea that the dynamical or causal perspective is the most fundamental one.

In short, unlike Rovelli’s or Mermin’s relationalist accounts of quantum mechanics which are still *dynamical* in nature, RBW employs the *spatiotemporal* relations via symmetries of the entire (past, present and future) experimental configuration and is thus fundamentally *kinematical*. And unlike other BW inspired accounts of quantum mechanics such as BCQM, RBW is truly acausal, adynamical and atemporal. As well, unlike other relational accounts, to use Einstein's language RBW characterized as a form of ontological structural realism is a complete break with the explanatory fundamentality of *constructive* (to use Einstein's term) and dynamical explanations.

While this interpretation of NRQM is strongly supported by the work of Kaiser, Anandan, Bohr, Ulfbeck, and Mottelson (referenced extensively herein), we are only now researching its implied adynamical, acausal ontology, whereby relations are fundamental to relata, at the level fundamental to NRQM via a spatiotemporally discrete action. Even though the formalism is incomplete, we have enough to speculate on its consequences for quantum gravity (QG). As with G4 and M4, the spacetime of general relativity (GR4) is an approximation which holds only in the large-order limit of spatiotemporally dense sets of relations. Therefore, we expect the GR4 approximation to break down in the realm of rarefied relations between two or more spatiotemporally dense sets of relations (each dense set requiring a metric per GR), e.g., the exchange of 'entangled particles' between stars in different galaxies[121]. In such cases, the everywhere separable metric of GR4 (providing continuously a distance in the empty space between galaxies) must be superceded by a discrete, non-separable metric *a la* that for spatial distance in Eq. 25. This implies the classical spacetime metric (for dense relations) is only a statistical approximation. Since spatiotemporal relationships can only be self-consistently defined in the context of trans-temporal objects, it must be the case that the stress-energy tensor is also a statistical approximation. Classically, the stress-energy tensor can be obtained by the variation of the matter-energy Lagrangian with respect to the metric, so Einstein's equations are probably a classical limit to the proposed self-consistency criterion for space, time and trans-temporal objects of our spatiotemporally discrete formalism (Figure 3).

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[121] This is distinct from the regime typically understood for QG, i.e., regions where *large* energy densities give rise to GR singularities. Of course, GR's physical singularities are avoided via discrete formalisms, such as that proposed herein, and they do not require a new limiting case for the discrete action, *a fortiori* they do not imply physics beyond that proposed by RBW.

QG so obtained would not be viewed as a fundamental theory of physics. Rather, QG in this context is just another limiting case of the (relevant) discrete action. Since the discrete action is to be obtained via a self-consistent definition of space, time and trans-temporal objects, there is no "problem of time" and we automatically have a background independent formulation. Thus, RBW produces a new direction for QG research which stems from "two things: the foundations of quantum mechanics and the nature of time," as predicted by Smolin.

ACKNOWLEDGEMENT

We are very grateful for extensive, insightful and detailed anonymous referee comments from reviewer # 1 on previous versions of the manuscript.

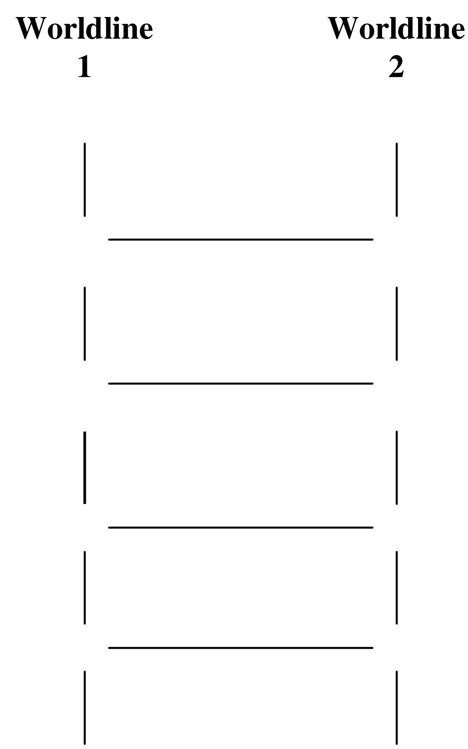
(Source materials for appendix 1)

1. B.C. van Fraassen, *Quantum Mechanics: An Empiricist View* (Oxford University Press, Oxford, 1991), p. 4.
2. L. Smolin, *The Trouble with Physics* (Houghton Mifflin, Boston, 2006), p. 256.
3. E. Schrödinger, *Ann. Phys.* **79**, 489-527 (1926).
4. A. Einstein, *Science* **91**, #5, 487-492 (1940).
5. D. Howard in *Potentiality, Entanglement and Passion-at-Distance*, R.S. Cohen *et al.* (eds.), (Kluwer Academic Publishers, London, 1997), pp. 114-115.
6. Ibid, pp. 124-125.
7. A. Einstein, *Deutsche Literaturzeitung* **45**, 1685-1692 (1924).
8. D. Howard, "Einstein and the Development of Twentieth-Century Philosophy of Science" to appear in *Cambridge Companion to Einstein*, from his website.
9. W.M. Stuckey, M. Silberstein & M. Cifone, to appear in *Phys. Ess.* **19** (2008; preprint quant-ph/0503065); in *Foundations of Probability and Physics 4*, (American Institute of Physics, Melville, NY, 2007), p. 412-421; chapter 11 in *Relativity and the Dimensionality of the World*, (Springer-Verlag, Germany, 2007, preprint quant-ph/0605039).
10. P. Lewis, *Brit. J. Phil. Sci.* **55**, #4, 713-729 (2004).
11. C. Rovelli, preprint quant-ph/9609002v2 (1997).
12. C. Rovelli, *Int. J. Theor. Phys.* **35**, 1637-1678 (1996).
13. N.D. Mermin, *Am. J. Phys.* **66**, 753-767 (1998).
14. J. Barrett, *The Quantum Mechanics of Minds and Worlds* (Oxford University Press, Oxford, 1999), p. 217.

15. J. Ladyman *et al., Everything Must Go: Metaphysics naturalized* (Oxford University Press, Oxford, 2007).
16. S. French & D. Krause, *Identity in Physics: A Historical, Philosophical and Formal Analysis* (Clarendon Press, Oxford, 2006), pp. 19-20.
17. R. Dipert, *J. Phil.* **94**, 329-358 (1997).
18. H. Leitgeb & J. Ladyman, Discussion Note: "Criteria of Identity and Structuralist Ontology," *Philosophica Mathematica*, forthcoming.
19. S. French in *From Physics to Philosophy*, J. Butterfield & C. Pagonis, (eds.), (Cambridge University Press, Cambridge, 1999), pp. 187-207.
20. S. French, *Synthese* **125**, 103-120 (2000).
21. E. Cassirer, *Phil. and Phenom. Research* **5**, 1-35 (1944).
22. A. Eddington, *The Nature of the Physical World* (Cambridge University Press, Cambridge, 1928).
23. E. Schrödinger, *Proc. Cambridge Phil. Soc.* **31**, 555-563 (1935); **32**, 446-451 (1936).
24. H. Lyre, *Stud. Hist. and Phil. Mod. Phys.* **35**, 643-670 (2004).
25. H. Weyl, *The Theory of Groups and Quantum Mechanics* (Dover, New York, 1931).
26. R. Geroch, *General Relativity from A to B* (University of Chicago Press, Chicago, 1978), pp. 20-21.
27. H. Price, *Time's Arrow and Archimedes Point* (Oxford University Press, Oxford, 1996), p. 260.
28. Ibid, p. 15.
29. Ibid, p. 224.
30. J. Cramer, *Rev. Mod. Phys.* **58**, 647-687 (1986).
31. P. Lewis, "Towards a Local Hidden Variable Theories," *Brit. J. Phil. Sci.* (forthcoming).
32. J. Barrett, "Relativistic Quantum Mechanics Through Frame-Dependent Constructions," *Phil. Sci. archives* (July, 2004).
33. Ibid Price (1996).
34. Ibid Cramer (1986).
35. Y. Aharonov, P. Bergmann & J. Lebowitz, *Phys. Rev.* **134B**, 1410-1416 (1964); A.C. Elitzur & L. Vaidman, *Found. Phys.* **23**, 987-997 (1993).
36. Ibid Cramer (1986), p. 661.
37. B. Dainton, *Time and Space* (McGill-Queen's University Press, Montreal, 2001), p. 119.
38. Ibid Stuckey *et al.* (2008).
39. Ibid Dainton (2001).
40. Ibid Howard (1997), pp. 124-129.
41. W. Pauli, *Scientific Correspondence with Bohr, Einstein, Heisenberg a.o.*, *Vol 2, 1930-1939*, edited by Karl von Meyenn (Springer-Verlag, Berlin, 1985), pp. 402-404.
42. G. Kaiser, *J. Math. Phys.* **22**, 705-714 (1981).
43. A. Bohr & O. Ulfbeck, *Rev. Mod. Phys.* **67,** 1-35 (1995).
44. J. Anandan, *Int. J. Theor. Phys.* **42**, 1943-1955 (2003).
45. Ibid Kaiser (1981), p. 706.

46. Ibid Bohr & Ulfbeck (1995), section D of part IV, p. 28.
47. Ibid, p. 24.
48. H. Brown & P.R. Holland, *Amer. J. Phys.* **67**, #3, 204-214 (1999).
49. J.V. Lepore, *Phys. Rev.* **119**, #2, 821-826 (1960).
50. See Brown & Holland's Eq. 6 (1999). For a derivation of Eq. 7 herein, assuming the acceptability of a phase difference such as that in Eq. 11 herein, see L. Ballentine, *Quantum Mechanics* (Prentice Hall, Englewood Cliffs, NJ, 1990), p. 49-58.
51. H. Brown in conversation (Apr 2005) with the authors while describing his work with P. Holland (Brown & Holland, 1999).
52. A. Bohr, B. Mottelson & O. Ulfbeck, *Found. Phys.* **34**, #3, 405-417 (2004); A. Bohr, B. Mottelson & O. Ulfbeck, *Physics Today* **57**, #10, 15-16 (2004). A very nice synopsis of their formal result is in the appendix of their 2004 *Foundations* paper.
53. H. Georgi, *Lie Algebras in Particle Physics*, *2nd Ed* (Perseus Books, 1999), p. 14.
54. Ibid, p. 25.
55. Ibid, p. 18.
56. W.M. Stuckey, arXiv quant-ph/0703039.
57. T. Toffoli, *Int. J. Theor. Phys.* **42**, #2, 363-381 (2003).
58. C.W. Misner, K.S. Thorne & J.A. Wheeler, *Gravitation* (W.H. Freeman, San Francisco, 1973), p. 364.
59. R. Shankar, *Principles of Quantum Mechanics*, 2nd Ed (Plenum Press, New York, 1994), p. 226.
60. Ibid Lewis (forthcoming), p. 20.
61. Ibid, p. 21.
62. A. Elitzur & S. Dolev in *Quo Vadis Quantum Mechanics*, A. Elitzur, S. Dolev & N. Kolenda (eds.), (Springer, Berlin, 2005a), p. 325-349; A. Elitzur & S. Dolev in *Endophysics, Time, Quantum and the Subjective*, R. Buccheri, A. Elitzur & M. Saniga (eds.), (World Scientific, Singapore, 2005b), p. 589-606.
63. Ibid (2005b), p. 593.
64. Ibid Elitzur & Dolev (2005a), p. 345.
65. Ibid Elitzur & Vaidman (1993).
66. Ibid Elitzur & Dolev (2005a).
67. L. Hardy, *Phys. Lett. A* **167**, 11-16 (1992).
68. Y. Aharonov & D. Rohrlich, *Quantum Paradoxes: Quantum Theory for the Perplexed* (John Wiley & Sons, NY, 2005), esp. section 6.4 and chapter 17.
69. N.D. Mermin, *Amer. J. Phys.* **49**, #10, 940-943 (1981).
70. A.C. Elitzur, S. Dolev & A. Zeilinger, arXiv: quant-ph/0205182.
71. Ibid Elitzur & Dolev (2005a), p. 344.
72. Ibid Bohr & Ulfbeck (1995).

Figure 4 (Figure 1, App. 1)



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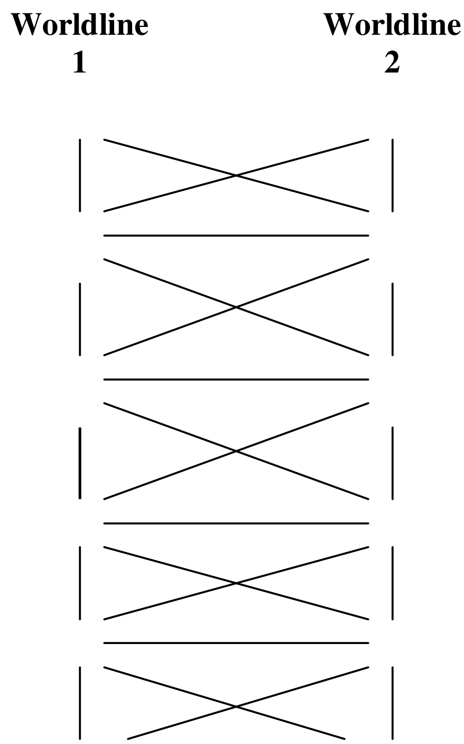
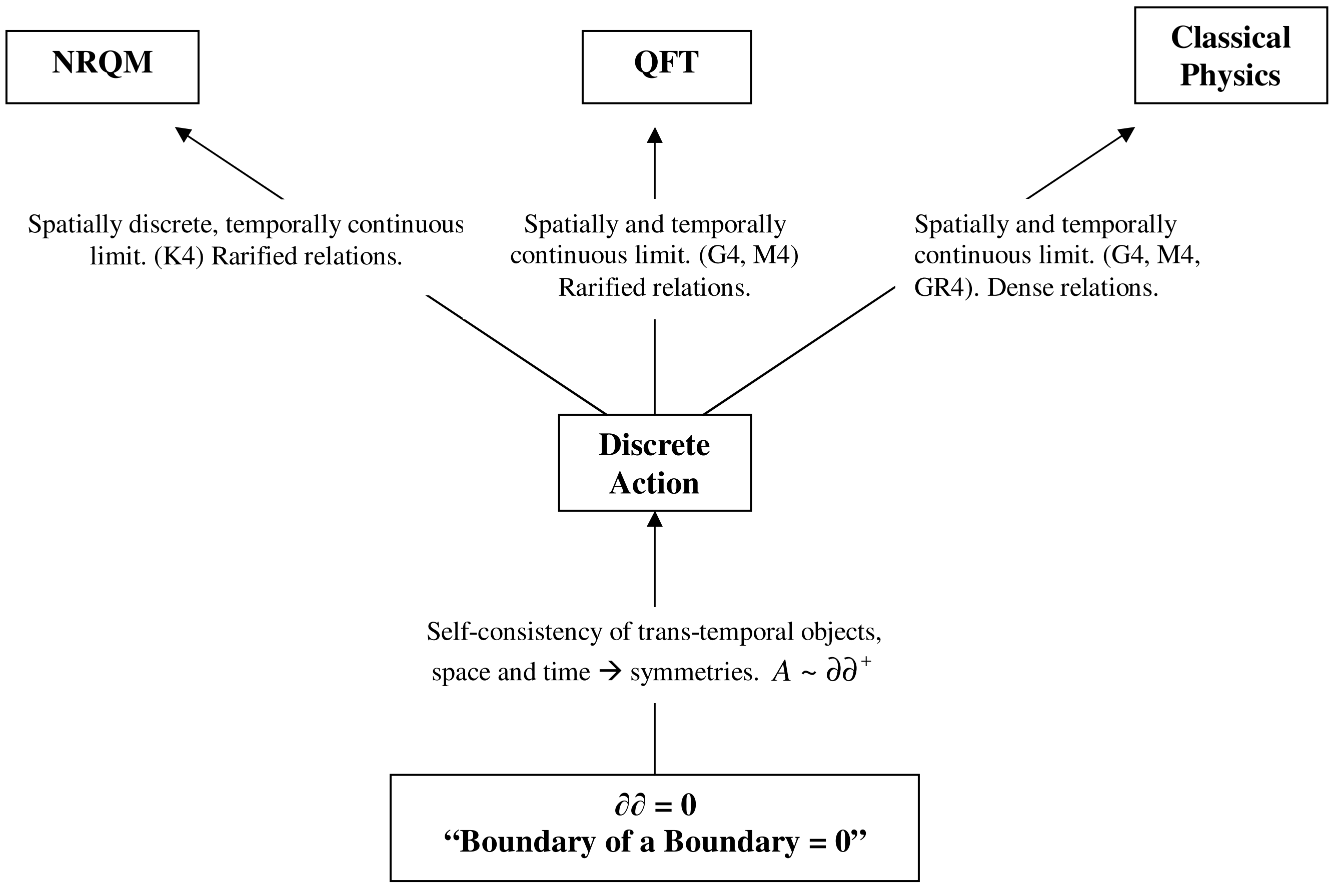


Figure 6 (Fig. 3, App. 1)



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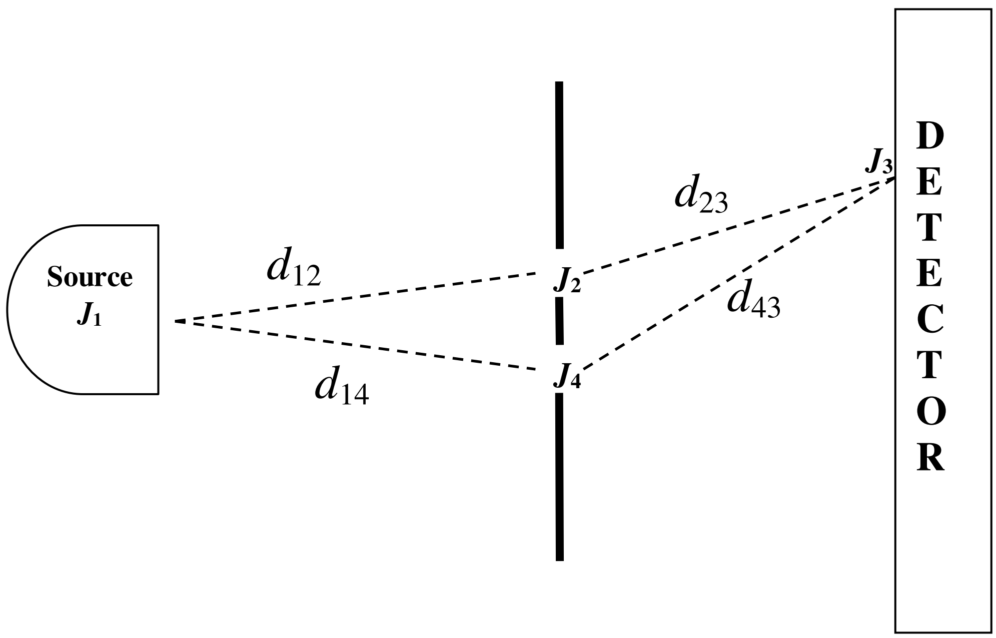

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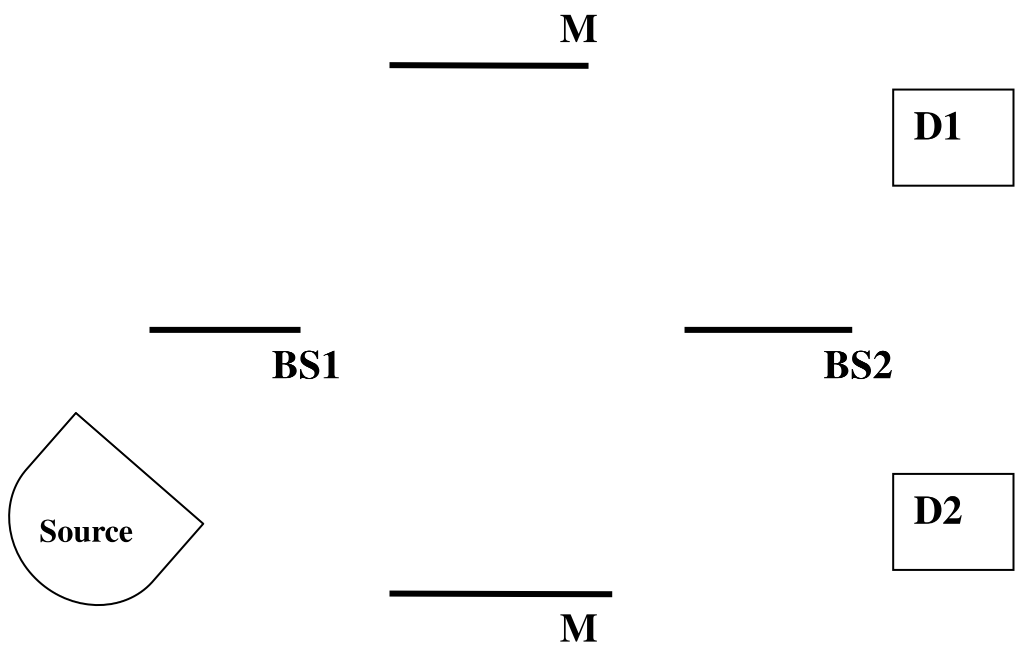

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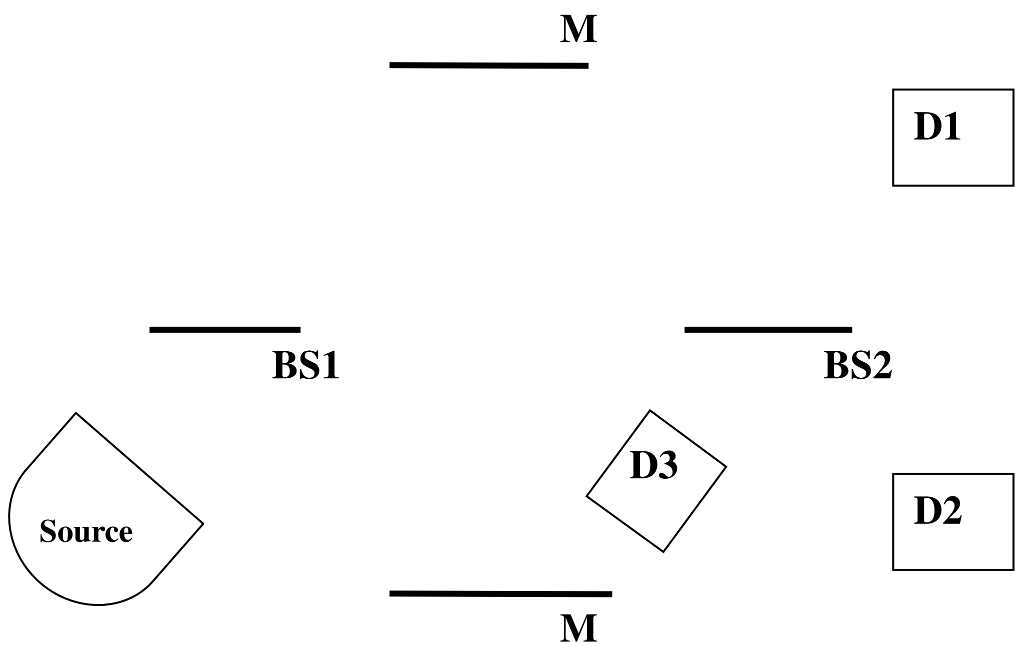

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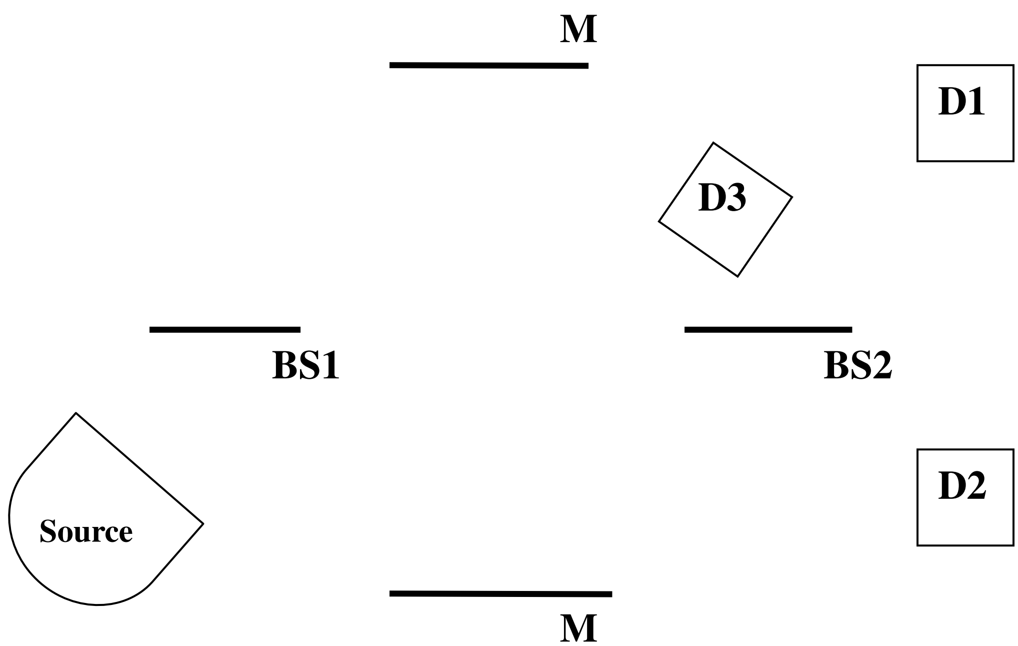

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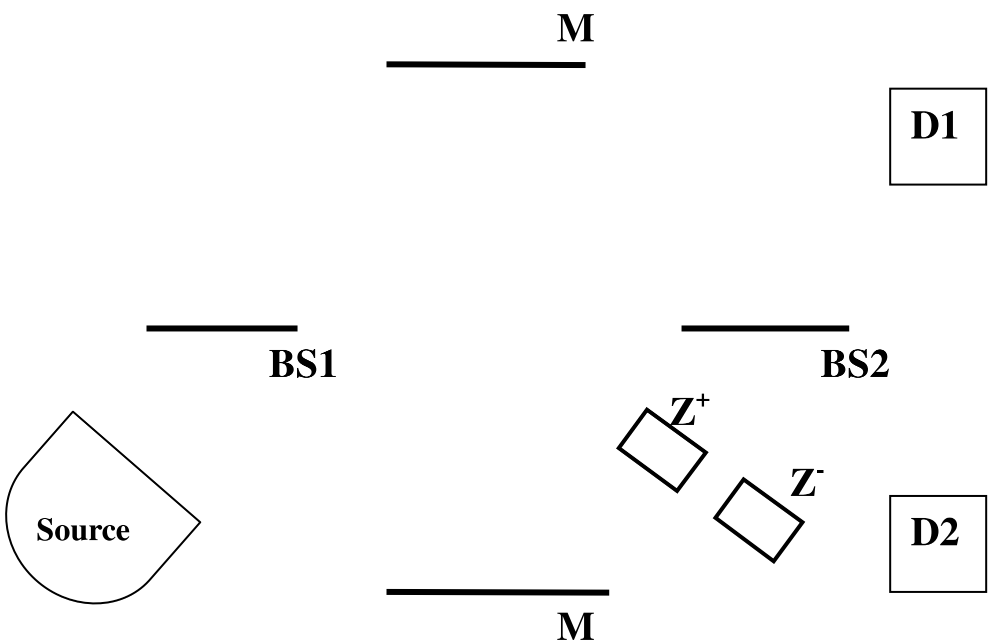

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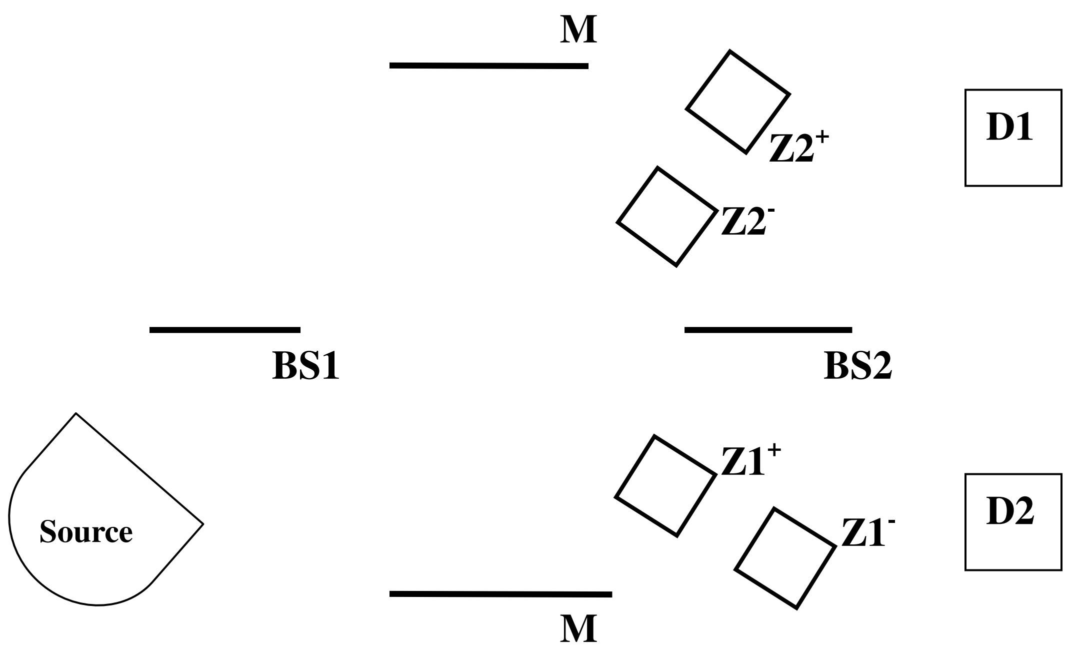

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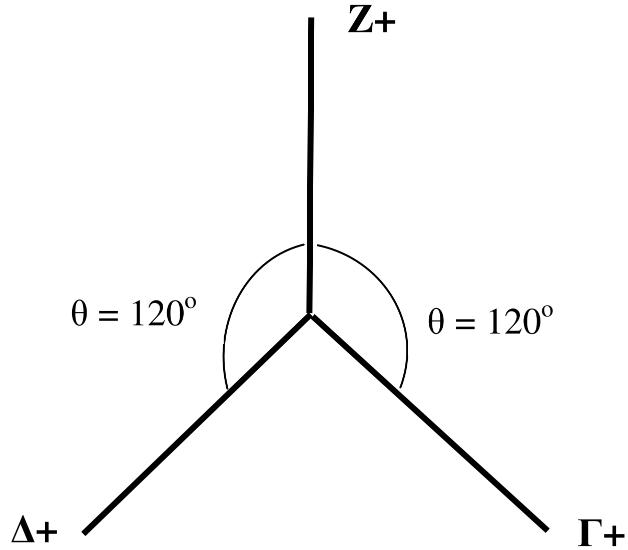

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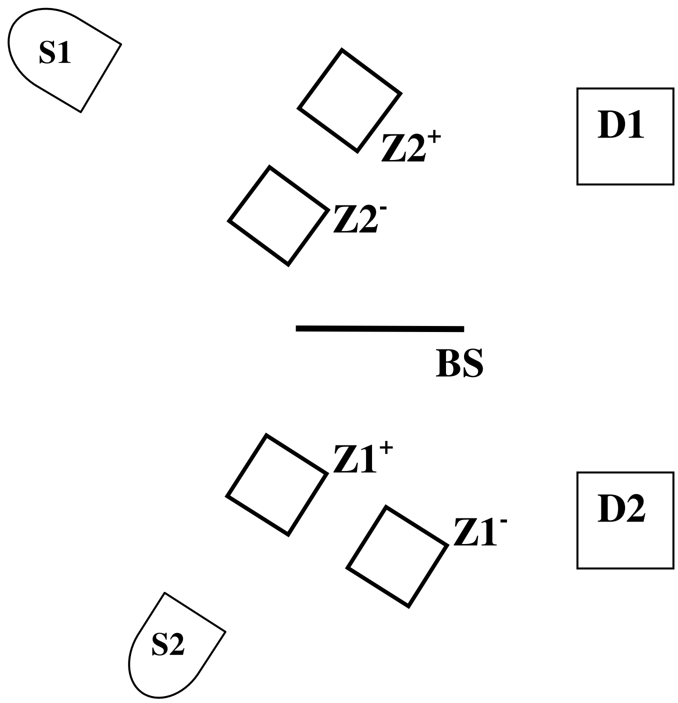

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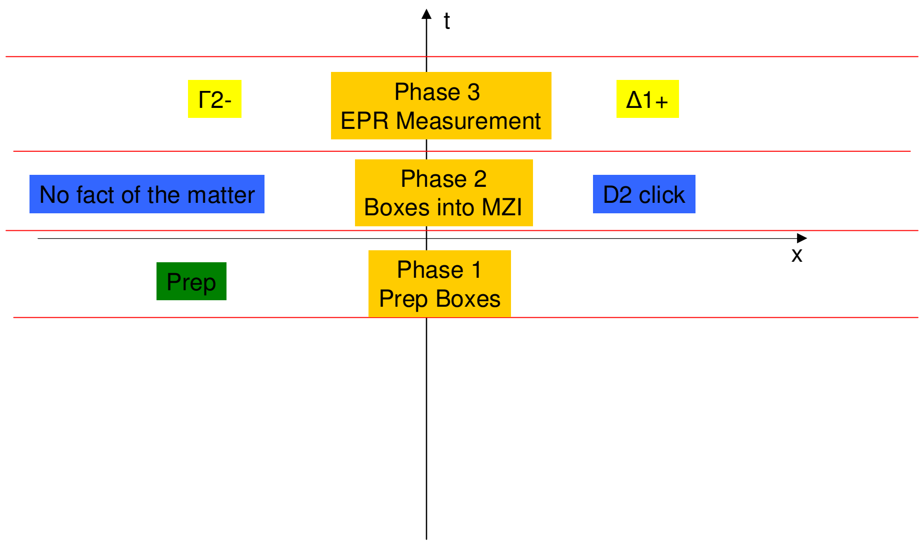


Figure 16 (Fig. 12, App. 1)

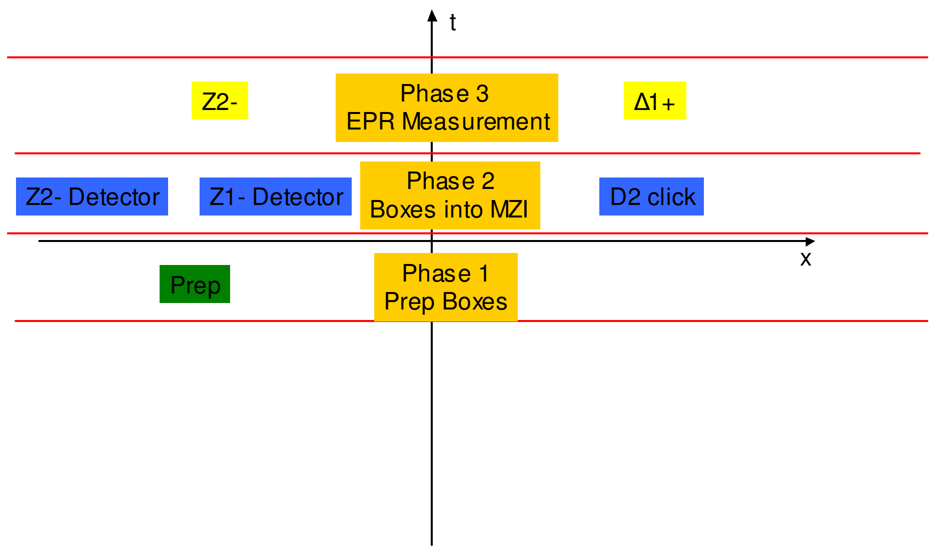
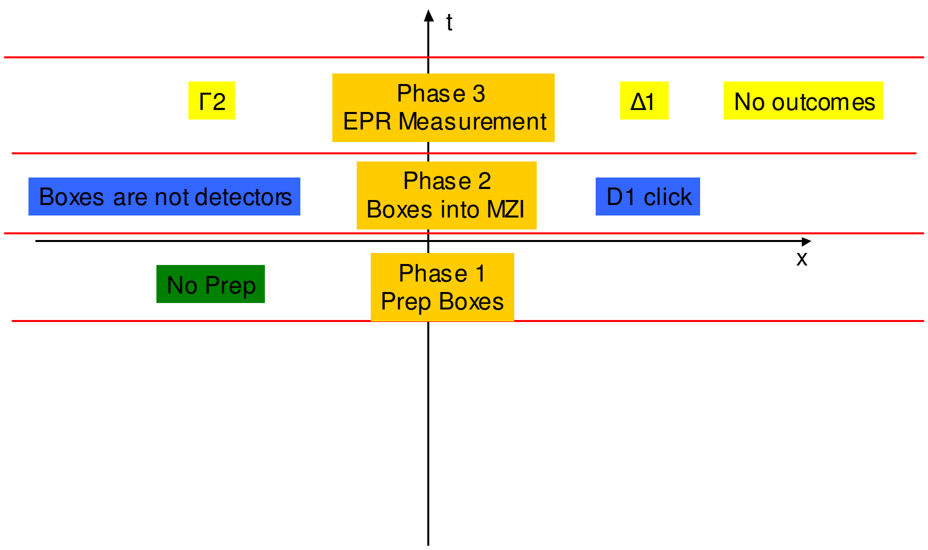


Figure 17 (Fig. 13, App. 1)



APPENDIX 2. Silberstein, Cifone and Stuckey (2008b), *Studies in History and Philosophy of Modern Physics* 39: 736—751.

Why Quantum Mechanics Favors Adynamical and Acausal Interpretations such as Relational Blockworld over Backwardly Causal and Time-Symmetric Rivals

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Abstract. We articulate the problems posed by the quantum liar experiment (QLE) for backwards causation interpretations of quantum mechanics, time-symmetric accounts and other dynamically oriented local hidden variable theories. We show that such accounts cannot save locality in the case of QLE merely by giving up "lambda-independence." In contrast, we show that QLE poses no problems for our acausal Relational Blockworld interpretation of quantum mechanics, which invokes instead adynamical global constraints to explain EPR correlations and QLE. We make the case that the acausal and adynamical perspective is more fundamental and that dynamical entities obeying dynamical laws are emergent features grounded therein.

Keywords. Time-symmetric quantum mechanics, blockworld, locality, backwards causation, relational blockworld, hidden variable.

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Introduction. We believe that (especially if one is interested in saving locality and thereby securing consistency with special relativity) certain quantum mechanical experiments like the quantum liar experiment (QLE) imply that quantum mechanics (QM) is deeply *contextual* in a way that calls into serious question *any* common-cause principle and *any* account of QM that relies on "interactive-forks" to explain, for example, Einstein-Podolsky-Rosen (EPR) correlations (Einstein *et al*., 1935). Our Relational Blockworld interpretation (RBW) has the explanatory capability to handle the contextuality (what we shall call "spatiotemporal contextuality") revealed in QLE while also preserving locality. RBW is an adynamical account of non-relativistic quantum mechanics (NRQM) that invokes *acausal and adynamical global constraints* and is therefore not in essential conflict with special relativity (SR). Unlike Huw Price's backwards causation QM (BCQM) account (Price, 1996) for example, we reject any kind of common-cause principle. Like BCQM and time-symmetric QM (TSQM)[122] and various local hidden variable theories[123], RBW is consistent with the denial of the "lambda-independence" assumption (that the *past* states of the hidden variables don't depend on their *future* states) in Bell's Theorem, but RBW does not rely on that fact to preserve locality.

Indeed, what will be made clear is that denying the lambda-independence assumption is not sufficient to preserve locality and furthermore that the other accounts all fail as complete interpretations, whether on more general grounds such as the measurement problem or in their lack of ability to explain QLE with locality intact. Section 1 will introduce the reader to RBW, section 2 will show why no extant account of BCQM, TSQM or local hidden variable theories more generally can clearly explain QLE while maintaining locality and section 3 will summarize the RBW acausal global constraint account of QLE.

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[122] There are many varieties of TSQM now in the literature. To name a few: there is the "two-vector" reconstruction of QM advocated by Aharonov and his collaborators (see e.g. Aharonov et al. 2002), which centers around the Aharonov-Bergmann-Lebowitz-rule (1964)—hereafter, "TSQM-ABL", the "transactional interpretation" (Cramer 1980, 1986), and the recent version of TSQM by K.B. Wharton (2007), which claims to be "the first attempt to combine the symmetric aspects of … previous proposals". Wharton's proposal applies "two symmetric boundary conditions [as with TSQM-ABL] onto a time-symmetric version of the Schrödinger equation [as with Cramer's interpretation]" (ibid., 160).

[123] See Lewis (2006) and (2007) for example.

1. *RBW: Radically Archimedean Physics*.

1.1. Blockhead Dreams. Others have suggested that we ought to take the fact of blockworld (BW) seriously when doing physics and modeling reality. For example, Huw Price (1996, p. 4) calls it the "Archimedean view from nowhen" and it has motivated him to take seriously the idea of a time-symmetric quantum mechanics and so-called backwards causation in quantum mechanics. As he says in his book defending BCQM: "the aim of the book is to explore the consequences of the block universe view in physics and philosophy" (Price, 1996, p. 15). Price is attempting to construct a local hidden-variables interpretation of NRQM that explains EPR correlations with purely time-like dynamics or backwards causation. According to Price, BCQM provides an explanation of the Bell correlations "which shows that they are not really non-local at all, in that they depend on purely *local* interactions between particles and measuring devices concerned. They *seem* non-local only if we overlook the present relevance of future interactions"(Price, 1996, p. 224). The key explanatory move that Price makes is to have information travel backwards along the light-cones of the two EPR particles, converging at the source of the entangled state. Presumably, this is the point in spacetime where the entangled state is "prepared." The picture we must think of is this: the future measurement interaction in separate wings of an EPR apparatus is the cause of the (earlier) entangled state, so the point at which they are created is the "effect" of a causal chain "originating" with the measurement interaction. That is, the effect of the causal chain originating with the measurement interaction is the directions in which the spin-components of the particles have determinate values at the point at which they are created. This is to put the point directly in terms of *backwards* causation. The arrow of causation does not point from one spacelike separated wing of the apparatus to the other, across *space*, but rather it points backwards in *time* to the point at which the particles are created—indeed, there are causal "influences" flowing in both directions along the particle trajectories.

The connection between BCQM or even time-symmetric accounts of the quantum and the BW seems straightforward at first: in a BW the state preparations and measurement outcomes are equally real, i.e., already "there" (which is not to say equally present). Thus, since a dynamic interpretation or explanation of the BW picture is secondary in some sense, one might as well claim the measurement outcomes "effect the state preparations" rather than the converse. However, upon inspection, it isn't obvious that BW entails BCQM or the reverse: a theory of causation is required for starters. Of course it may seem trivial to explain the outcomes of quantum experiments (or anything else) using the BW. After all, one could answer *any* question in this vein by saying something like "it's all just there in the BW, end of story" (see Barrett 2005). In order to avoid trivializing the BW explanation, BW motivated interpretations of NRQM invoke clever devices such as time-like backwards causation, advanced action and the two-vector formalism. Do these beautiful and clever devices really avoid the charge of triviality and do they really involve the BW hypothesis essentially? An answer in the negative will be given in section 2.

We can't speak for Price and others, but for us the BW motivation is not just about preserving locality, nor even just peaceful co-existence with the relativity of simultaneity, but rather it is our belief that taking the BW seriously suggests the possibility for radically "Archimedean" solutions to many of the problems in QM, such as how to interpret EPR correlations and the measurement problem. Thus we are bothered by the fact that BCQM and TSQM explanations are no less *dynamical* than standard quantum mechanics, which is puzzling if part of the original blockworld motivation for such accounts is that the BW lacks *absolute* change and becoming. As far we know, only Cramer speaks to this worry directly. Cramer notes that the backwards-causal elements of his theory are "only a pedagogical convention," and that in fact "the process is atemporal" (Cramer, 1986, 661). In all fairness, Price (2007) does emphasize the "perspectival" nature of causal explanations. BCQM and the like, even having acknowledged the potential explanatory importance of BW, have not, as will become clear, gone far enough in their atemporal, acausal and adynamical thinking. Whereas such accounts are willing to think backwardly, temporally speaking, it is still essentially *dynamical, temporal* thinking. All of this poses a dilemma, to exploit BW in an *essential* and *non-trivial* way to explain quantum effects while preserving locality. As we will see in sections 2 and 3, dynamically unfettered BW thinking will be mandatory for explaining QLE.

We rather believe the key to rendering a BW explanation *essential* and *nontrivial* is to provide an algorithm for the relevant BW construction. Thus, the answer to: "Why did event X follow Y and Z?" is not merely, "Because X is already 'there' in the future of Y and Z per the BW," but as we will illustrate, "Because this must be the spatiotemporal relationship of X, Y and Z in the BW per the self-consistent definition of the entities involved in X, Y and Z." If one chooses to read dynamical stories from a BW picture, they may where necessary or feasible. However, BW descriptions are not limited to the depiction of dynamical/causal phenomena, so they are not constrained to dynamical/causal storytelling. In the following passage Dainton paints a suggestive picture of what it means to take the BW perspective seriously both ontologically and methodologically:

> Imagine that I am a God-like being who has decided to design and then create a logically consistent universe with laws of nature similar to those that obtain in our universe…Since the universe will be of the block-variety I will have to create it *as a whole*: the beginning, middle and end will come into being together…Well, assume that our universe is a static block, even if it never 'came into being', it nonetheless exists (timelessly) as a coherent whole, containing a globally consistent spread of events. At the weakest level, "consistency" here simply means that the laws of logic are obeyed, but in the case of universes like our own, where there are universe-wide laws of nature, the consistency constraint is stronger: everything that happens is in accord with the laws of nature. In saying that the consistency is "global" I mean that the different parts of the universe all have to fit smoothly together, rather like the pieces of a well-made mosaic or jigsaw puzzle (Dainton, 2001, 119).

Does reality contain phenomena which *strongly suggest* an acausal-global-constraint-BW-algorithm? According to RBW, standard EPR correlations, other quantum oddities such as eraser experiments and the delayed choice experiment for example provide reason to answer in the affirmative, but QLE demands such an answer especially if locality is to be preserved and consistency with SR maintained. NRQM *a la* RBW is one algorithm for depicting the self-consistent placement of such phenomena as EPR and QLE in a blockworld, as will be illustrated via the quantum liar experiment itself. Likewise, attempting to explain all QM phenomena via dynamism precludes certain unique blockworld explanations rendered by RBW (e.g., Stuckey *et al.*, 2008). Thus, the dynamical perspective is overly constrained because it constitutes only a proper subset of all possible BW-compatible explanations;

dynamical reality is only a proper subset of a spatiotemporally contextual reality given globally and some QM phenomena are "mysterious" simply because they're not elements of that dynamical subset, such as QLE. The next section provides a brief overview of RBW[124].

1.2. Overview of RBW. RBW provides an account of QM that resolves all the foundational issues therein (see Stuckey *et al*. 2008 for details). RBW rejects any kind of common-cause principle, i.e., the claim that every systematic quantum correlation between events is due to a cause that they share whether in the past or future. QM detector clicks are not evidence of microscopic dynamical/diachronic entities (with "thusness" as Einstein would say) propagating through space and impinging on the detector. Rather, detector clicks evidence rarefied subsets of geometric relations *comprising* the source, detector, beam splitters, mirrors, etc. in the entire worldtube of the experimental arrangement from initiation to outcomes (as in the case of entanglement), in an "all at once" fashion. Because for RBW, to borrow from Mermin (1998, p. 755), it is "relations all the way down" (relations not relata are the fundamentals as we ultimately express graph theoretically in Stuckey *et al*. 2008) and because our account is foundationally adynamical in that blockworld is *essential* to the story (the deepest explanation for quantum phenomena is not Schrödinger dynamics, i.e., we take the entire history of a system as the explanans and explanandum via acausal global determination relations), we call it the Relational Blockworld. Dynamical entities and dynamical laws are emergent features in our view, not fundamental[125]. Unlike the Everettian "quantum block" of Saunders (1993), RBW does not require the actuality of all outcomes and indeed adopts a kind of neo-statistical interpretation with respect to Schrödinger dynamics [126].

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[124] Phenomena begging to be explained in terms of acausal and adynamical global constraints are not limited to the quantum. For example, we think this is the right way to explain closed-time-like curves (CTCs) as well, rather than as a failure of dynamical determinism as such.

[125] See Stuckey et al. (2008) for the RBW account of an adynamical theory (formalized using discrete graph theory) fundamental to both QM and GR that unifies the two and from which both "emerge" in an adynamical fashion.

[126] See Stuckey et al. (2008) for the complete details on exactly how RBW fully resolves the QM measurement problem, but suffice it to say that the wavefunction description of a quantum system can be interpreted statistically because we now understand that, as far as measurement outcomes are concerned, the Born distribution has a basis in the spacetime symmetries of the experimental configuration. Each "click," which some would say corresponds to the impingement of a particle onto

The ontology of RBW is best characterized as a form of ontological structural realism (see Stuckey *et al*. 2008 for details). While non-separable, RBW upholds locality in the sense that there is no action at a distance, no instantaneous dynamical or causal connection between space-like separated events and there are no space-like worldlines. As we said, RBW preserves locality with a non-separable geometric ontology of relations. The next section shows why QLE is problematic for BCQM, TSQM and local hidden variable accounts.

2. ***Quantum Liar: Trouble for BCQM, TSQM and Local Hidden Variables*****.** In Elitzur and Dolev's (ED) "quantum liar" experiment (Elitzur and Dolev, 2005), extrapolating from the work of Elitzur and Vaidman (1993) and Lucian Hardy (1992, 1993, 1994), ED show how "atoms" may be brought into an EPR state for which there is *no* causal connection between them in the past *or the future*. To see this, consider Figs. 1 and 2, as discussed by Elitzur and Dolev (2005). This is an example of an "interaction free" measurement (IFM), in the sense that no interaction is required to extract information about the atom's state in this situation. We can summarize QLE by saying that it combines EPR-entanglement *a la* IFM (defying any common-cause principle) with a delayed-choice component. As follows, we can divide QLE into three distinct spatiotemporal phases: (1) prepare the boxes with the atoms, (2) place the boxes in the Mach-Zehnder interferometer (MZI) and turn on the lasers (Fig. 2), (3) remove the boxes after a D click and perform spin measurements on the atoms therein (if there is a C click or no click, then you must return to phase 1 and begin again). To describe the first phase of the experiment, let there be two atoms in the $|X+\rangle$ spin state, which by QM we know is a superposition of its Z-spin states,

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a measurement device with probability computed from the wavefunction, corresponds to spacetime relations in the context of the experimental configuration. The measurement problem *exploits* the possibility of extending the wavefunction description from the quantum system to the whole measurement apparatus, whereas the "all at once" description according to RBW already includes the apparatus via the spacetime symmetries instantiated by the entire experimental configuration from initiation to outcomes. The measurement problem is therefore a non-starter on our view. The measurement problem arises because of the assumption that the dynamics are the deepest part of the explanatory story, the very heart of quantum mechanics, an assumption RBW rejects. In short, RBW provides a kinematic (pre-dynamical) solution to the measurement problem.

Z– and Z+. Let this superposition be spatially divided into two separate boxes, one box containing the Z+ outcome and one box containing the Z- outcome. Each atoms' spin is now spatially divided according to its respective (though superposed) spin-state, Z– and Z+. To describe the second phase of the experiment, let there be two coherent laser-sources (denoted S_1 and S_2) directed at two distant detectors (called *D* and *C*); and let there also be a beam-splitter between the beams and the detectors (equidistant between them). We arrange the laser-sources such that one beam passes through one box: S_1's beam through Z_1+ while S_2's beam passes through Z_2 –. With no potentially obstructing atoms in the beams' way, the lasers are set to constructively interfere at path *c*, while destructively at path *d*. As ED show, the mere uncertainty in "which box" information suffices to entangle the atoms in the familiar EPR state when there is a D click:

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left(|Z+\rangle_1 |Z+\rangle_2 + |Z-\rangle_1 |Z-\rangle_2\right)$$

We can infer this because: 1) a D click entails one and only one of the beams is blocked thereby thwarting destructive interference, 2) a D click implies that one of the atoms was in its 'blocking box' and the other in its 'non-blocking box' and thus 3) the mere uncertainty about which atom is in which box entangles them in the EPR state as evidenced by the table of outcomes below:

Particle	Particle	C-click	D-click
Z+	Z+	50%	50%
Z+	Z-	0%	0%
Z-	Z+	100%	0%
Z-	Z-	50%	50%

Table 1

Given phase 2 has produced the state in Eq. 1 per a D click, we conduct the third phase of the experiment which is to "recombine" the spatially separated boxes (say, under a reverse magnetic field) and make random spin measurements on the atoms in the Γ, Δ and Z directions (Fig. 4) as detailed by Mermin (1981). We will repeat phases 1-3 many times such that all combinations of the three spin direction measurements are performed. If we amass the results from all trials and check for correlations, we find that Bell's inequality is violated which indicates the Z component of spin *cannot* be inferred as 'a matter of definite but unknown fact' in trials prior to Γ and/or Δ measurements. This is not consistent with the apparent "matter of fact" that a "silent" detector must have existed in one of the MZI arms in order to obtain a D click, which entangled the atoms in the first place.

As ED point out, a "puzzling situation now emerges:"

> In 5/9 of the cases … (assuming random choices of measurement directions) one of the atoms will be subjected to a Z measurement – namely, checking in which box it resides. Suppose, then, that the first atom was found in the intersecting box [Fig. 2]. This seems to imply that *no photon has ever crossed that path, which is obstructed by the atom*. But then, by Bell's proof, the other atom is still affected by the measurement of the first atom. But then again, if no photon has interacted with the first atom, the two atoms share no causal connection, in either past of future! (Elitzur and Dolev, 2005, 343).

The moral of this experimental possibility is that entanglement may be generated when there is no interactive point in spacetime by which we may argue that the pair was coordinated. In other words, the mere fact that the particles are arranged in a certain way, in conjunction with the fact that a photon's path might effectively "measure" in which box our atoms reside, suffices to generate entanglement. But as should be clear by now, the situation is weirder than that. To put the point more acutely, Elitzur and Dolev (2005, p. 344) conclude their exposition of the paradox with the observation that: *The very fact that one atom is positioned in a place that seems to preclude its interaction with the other atom leads to its being affected by that other atom.* In other words, *there must be a fact of the matter concerning the Z spins* (i.e., a fact of the matter about the positions of the atoms in the boxes) *in order to produce a state* (entanglement via a D click) *in which certain subsequent EPR spin measurements imply there was no fact of the matter for the Z spins.* One is tempted to say that the atoms are entangled IFF they are not.

Let's use the QLE experiment to define a particular kind of contextuality which is contained in QM – *spacetime* contextuality – and distinguish this kind from others, which are more properly called contextuality of quantum states or property-contextuality[127]. Spatiotemporal contextuality implies that entanglement can be generated via the spatiotemporal configuration of the experimental set-up in a way not explicable by any kind of common-cause principle and whose deepest explanation therefore requires invoking the entire actual history of the experiment in question. The spacetime contextuality embodied by QLE poses serious problems for BCQM, and raises very important questions for the view. As will become even clearer in section 3, whether or not Z spin has definite values is a function of *spatiotemporal context*, a fact that would never be revealed were one handed the boxes for phase 3 measurements without knowledge of how the EPR state had been created in phases 1 and 2.

The way that BCQM was envisioned by Price seems to rely – crucially – on EPR experiments of an “interactive-fork” sort, as we can easily see in Fig. 3. Such configurations allow for a natural causal interpretation of the violation of lambda-independence in the sense that we can take there to be information *causally transmitted* along the back light-cone of the particles that will be (separately) measured. Causation is a backwards, time-like, entity-/particle-carried sort of process. In this case, as Price says, an explanation of EPR:

> does not seem to call for any new field or bearer of the influence that one measurement exerts on another. If we think of the fate of a particle as a property of that particle – a property which has a bearing on the results of its interaction with its twin – then the particles themselves ‘convey’ the relevant influence to its common effect at the point at which they separate. (Price, 1996, 247).

The obvious problem QLE poses is the lack of an interactive-fork – how does atom #1 “know” what atom #2 is doing? How is the correlation going to be (locally) pulled off if the particles share no causal connection in the past or future? We think this worry might rule out BCQM and TSQM accounts in principle, but to be charitable perhaps some specific mechanism could overcome it.

[127] E.g., the contextuality associated with the Kochen-Spekker Theorem. Notice that “spatiotemporal contextuality” may be related to KS-type contextuality, but since we’re not interested in the properties of quantum states per se, but rather their placement in the context of a particular spatiotemporal arrangement (i.e., QLE), spatiotemporal contextuality is distinct from what we can call property or “quantum-state” contextuality.

However, since no ontology is supplied, we just don't know how the trick is going to be pulled off: the devil is in the details. As Callender pointed out, Price's BCQM suffers from not being a full-on interpretation: it's better called an "interpretation schemata" (Callender, 1998). To be a full-on interpretation requires that:

> the QM formalism [be supplemented] with an ontology and with some plausible physical laws describing how this ontology behaves. This is a highly non-trivial task, requiring that one devise a 'natural-looking' theory that reproduces the phenomena described and predicted by QM. (*ibid.*, p.155).

And without this, we have no physical story which underwrites the probabilities – we have no idea what the probabilities are probabilities of. It's one thing to show – as Price does – that probabilities satisfying locality (i.e., by violating lambda-independence) are mathematically possible in principle with the addition of *some* hidden variable to the QM formalism. But it is quite another to show what that hidden variable physically is (that's what an ontology does) such that we may understand how the probabilities are *physically realized*[128]. One thing seems certain, any account of BCQM, TSQM, etc., that requires interaction (some sort of common-cause principle) such as an "interactive-fork" to explain entanglement will run afoul of QLE.

There exist at least three potential instances of BCQM-type views that (possibly) meet the desiderata for a specific mechanism suggested above: Cramer's "transactional" interpretation (TI) and a version of Time-Symmetric QM centered on the now well-known "ABL rule," which we'll denote as "TSQM-ABL." The last, and perhaps most interesting, is Peter Lewis' recent local hidden-variables theory based on the "many-histories" approach to QM, which he calls the "single-history" interpretation based on the fact that he is able to dispense with all but a single-history – the actual one. Unfortunately, Cramer and TSQM fail to provide us with an

[128] Recall Butterfield's comment that "physical reality requires something more than just successfully modeling the given statistics" and his important distinction between "mathematically possible" probabilities and "physically real" probabilities. See Butterfield (1992, p. 78); see also Dickson (1997, p. 143ff.) for a discussion. BCQM certainly demonstrates the former, whereas the latter is more obscure – and especially in the case of QLE.

ontology that obviously and clearly satisfies Einstein locality, whereas Lewis' view faces a number of troubling dilemmas.

2.1. TSQM-ABL and the Transactional Interpretation. Both Cramer's "transactional" interpretation and the "two-vector" or the TSQM-ABL interpretation supply a concrete physical story to the abstract BCQM interpretation schemata. TSQM-ABL applies a time-symmetric boundary condition to *individual quantum states*, and thus is open to a worry about whether or not there are any non-local influences exchanged between entangled elements at space-like separation in the context of the puzzling QLE. This is because TSQM-ABL is (most plausibly) read as an "influences" instance of BCQM, as Ruth Kastner notes (1999, p. 237)[129] and because it's unclear how the time-symmetric boundary condition *itself* is sufficient to explain the acausal local generation of EPR in QLE – especially if we stick to ordinary particles and their behavior according to the dynamics of TSQM, as most TSQM-ABL advocates do.

According to TSQM-ABL, an individual quantum state is one that has been pre- and post-selected, that is, as one to which we have applied an initial and final boundary condition (the initial boundary condition being the preparation event itself, and the final event its measurement). Thus, when we have an EPR correlation, if the TSQM-ABL view is to save locality, it must be the case that upon measurement, information about that measurement travels back in time to converge on the EPR state, thereby supplying that state with the requisite future boundary condition. In the case of QLE, such a convergence point in spacetime is absent, so TSQM-ABL faces the same general worry that was raised for BCQM at the beginning of this section: how do particles that share no causal connection in the past or the future communicate this future boundary condition to each other? By what local process is the time-symmetry of this EPR state generated?

Cramer's view is slightly different on this score: his is one where the wavefunction is taken realistically and time-symmetrically. In the case of a simple

[129] Note that Kastner, following Sharp and Shanks (1993), argues quite convincingly against a counterfactual reading of the ABL rule central to TSQM-ABL, calling into question a counterfactual dependency notion of causation in this case (or at least suggesting that an account of causation in terms of counterfactual dependency cannot be tied to ABL itself). This seems to block the possibility of deploying Lewis' preferred theory of causation for TSQM-ABL (see discussion below of Lewis' view).

EPR set-up (Fig. 3), we have an "offer-wave(function)" and a "retarded-wave(function)" sent out from the point where the initial wavefunction (corresponding to the EPR state) is emitted (the source) and the point where it is absorbed (the detectors). A "transaction" is completed once both "offer" and "retarded" waves meet and they bounce back and forth until all the boundary conditions are met. But notice that this view simply puts the burden of saving Einstein locality onto the wavefunction itself. Consider the case of QLE in Fig. 2 (granting for the moment that Cramer's view can be coherently applied to this particular case). The crucial question is, what brings about the EPR correlation when neither correlated partner has shared a causal connection anywhere in spacetime? Even if the wavefunction of the photon brings about the EPR correlation between atoms 1 and 2, the photon's wavefunction will be spread out in spacetime, encompassing both atoms. Thus, if the photon's wavefunction is the medium of transmission, or the mechanism that brings about the correlation, it is non-local: one region of spacetime is non-locally connected to another via the photon's wavefunction. Given that neither atom shares a connection with the other in the past or future, then this looks to be, again, a case of side-to-side non-locality, not merely "temporal" non-locality. The upshot of all this is that denying lambda-independence (what Price calls 'μ-innocence') is not sufficient to save locality.

2.2. *Lewis' "single history" approach*. Lewis' view (2007) lends itself to two very different interpretations: (1) a toy model of a universal wavefunction fundamentalism view without collapse (based on Gell-Mann and Hartle's (GH) "many histories" interpretation, which is itself a variation of Everett's view) modified by a hidden-variable. It is a toy model in that it models time as discrete at a scale at which there is no physical motivation for doing so. He doesn't say what the hidden variables are explicitly, but rather regards the many-histories formalism as a recipe for generating (time-discrete) hidden variable theories, and says "pick one of the hidden variable theories so generated." Regarding the hidden variable he suggests the following: use the many-histories recipe to make the mass density in every 10^{-5} cm^3 determinate every 10^{-5} seconds (i.e., the "Ghirardi ontology"). Thus we have a wavefunction evolving continuously without collapse, in addition to a stop-motion coarse-grained history, which attaches determinate mass densities to little boxes every $10e^{-5}$ seconds. The theory generates many such histories and a probability distribution over them, but only one such history is actual. The hidden variable (the stop-motion history) puts macroscopic objects at determinate locations and thus determinate measurement results are achieved.

Though he doesn't say so explicitly in the article, Lewis admits he will need the actual history of the entire universe (past, present and future) as the hidden variable in order to preserve locality. This will yield a superdeterministic picture *a la* Bell in that the past doesn't *determine* the future, but there are facts about it anyway. As he says, it's (trivially) local, but violates Bell's independence condition. Lewis supplies a recipe for picking out a *single* history as the *actual* one, from the many sets of mutually decoherent histories implied by the GH view (Lewis, 2007, p. 1463). While the details of this recipe are not relevant here, what is important is how Lewis' view satisfies locality. Lewis claims that the single-history approach "straightforwardly ascribes probabilities to the histories" and that "since there is no interference between histories [in a simple case where the universe consists of just a single EPR experiment] … [the] probabilities are exactly the standard Born probabilities, and hence violate the Bell inequality" (*ibid*., p. 1466). Lewis also shows that his view satisfies "side-to-side" locality: the probability of the outcomes of measurements on the left-side of an EPR set-up are independent of those on the right-side (recall Fig. 3). The view circumvents Bell's theorem by denying "independence" in the sense that:

> the hidden variables that determine the outcome on the left are not independent of the orientation of the measuring device on the left. More precisely, the hidden variables in the single-history case – constituted by the actual history of the universe – only determine the outcomes for measurements that are actually performed along that history. (*ibid*, p. 1466.)

The trick that gets Lewis out of the interactive-fork problem faced by BCQM is that he takes causation to be merely *counterfactual dependency* in the case where others wish to postulate a backwards causation "mechanism," influence or process. He writes: "since the current hidden variables of the particles would have been different if the future measurements on the particles had been different, one should say that the future measurements causally influence the current hidden variables" (*ibid.*, p. 1467) in the sense that the states of the hidden variables counterfactually depend on future measurement acts. Thus, no influence need be realized by particles, or some new sort of entity; no information needs to be physically carried along a path in spacetime – causation *qua* counterfactual dependence is all the causation you need.

As Lewis suggests himself, there are two ways to interpret even *this first horn* of his interpretative dilemma (interpretation 1): as an instance of BCQM *a la* counterfactual causal dependence or take the violation of "independence" to be "an instance of an acausal constraint on the distribution of events in the universe" (*ibid.*, p. 1466). The first interpretation strikes us as no less trivial than merely asserting the fact of BW, causation as counterfactual dependence is metaphysically cheap and does not advance the actual physics of the situation per our previous discussion. Lewis might reply that the many histories machinery makes it non-trivial but unfortunately several tough questions arise here. First and foremost, when it comes to explaining quantum phenomena and preserving locality, *why exactly* does the many histories machinery make his view any less trivial than merely asserting BW as the explanation? There appears to be no story here about how the wavefunction *explains* or *gives rise to the* actual history. Suppose we want to know what makes one and only one of the many histories actual from the set of possible histories? On Lewis' view this is just a brute fact. Suppose we want to know what underwrites or explains the counterfactual dependencies invoked to save locality? Same answer, those relations are just a brute fact. Since this is presumably a form of wavefunction fundamentalism the lack of answers here is distressing. Furthermore, since he acknowledges the necessity and reality of BW and blockworlds by definition don't *come into* and *go out of* existence, it's hard to see in principle how the universal wavefunction could *explain* its existence in any robust or productive sense of explanation, that is, it's very hard to resist being a Humean about dynamical laws in a BW setting. Lewis can and does say the following about the wavefunction: The quantum state determines the set of histories via the Gell-Mann-Hartle formalism—one history is actual (end of story). The wavefunction *encodes* entanglement, which functions as a constraint on histories, but beyond that the wavefunction *explains* nothing. Of course, even a wavefuction anti-realist or instrumentalist can sign on to this talk about “encoding,” so one would like more. Finally, it seems like the hidden variable (mass density in small cubes) is doing the real ontological work on Lewis’ view.

Wavefunction fundamentalism aside, if talk of “counterfactual dependence” is going provide a *non-trivial local explanation* for EPR and QLE, then we are owed a story as to what *underwrites* the dependency. More generally, the merely *philosophical* move of employing a counterfactual account of causation in this context does not solve the real physical and metaphysical quandary as to whether or not Einstein causality is violated by EPR and QLE—in order to answer this question we need an interpretation with the physical details elaborated. That is, both counterfactual accounts of causation and the BW are compatible with both local and non-local interpretations of QM and neutral with respect to whether or not EPR correlations conflict with the relativity of simultaneity.

The second “interpretation” (acausal global constraints) of interpretation (1) of Lewis’ view obviously strikes us as the right way to go in principle but again, to avoid the charge of triviality and all the other problems of the first interpretation of (1), one must *underwrite* the global constraints in an acausal and adynamical fashion and that means providing some sort of account (such as an adynamical and acausal hidden variable other than the universe itself!) that supercedes or relinquishes wavefunction realism and the like. What gives rise to the locality preserving acausal global constraints (what are they and where do they come from) such that the measurement problem, etc., is not a worry? Whatever the answer to this question, *by definition*, it can’t be found in the dynamics (e.g., the wavefunction) alone—on any interpretation of the dynamics. Not only does invoking acausal and adynamical global constraints to save locality entail providing some story fundamental to the dynamics, but on pain of triviality it also requires something fundamental to the fact of BW itself. And again, BW by itself does not imply locality, it depends on the nature of the BW in question. In other words, Lewis provides no story of what the locality preserving acausal global constraints are, merely that they are encoded by the wavefunction.

Lewis in conversation has kindly suggested just such an alternative and that's interpretation (2) of Lewis. On this account, the claim is that classical macroscopic objects (tables, chairs, pointers) supervene on the hidden variables and not on the wavefunction. Given the mass density ontology, the fundamental stuff that makes up the observable world is a mass density distribution, not the wavefunction. On this second interpretation, the wavefunction is just a convenient way of expressing the constraints on the possible histories of the world, nothing more. The possible histories of the world are possible ways the mass density distribution could evolve, one of them is actual—that's what underlies everything we see. Obviously, this is *not* a form of wavefunction fundamentalism. There is just a single history of the world, and the wavefunction doesn't *explain* it in any causal or production sense. Rather, the wavefunction explains our epistemic situation as creatures in this BW.

It should be clear that Lewis (2) has many of the same problems as Lewis (1). We still only know that the wavefunction encodes various kinds of information and explains our situatedness in the BW, but we don't know why this is the case, and we don't know what if anything beyond mere phenomenology connects the wavefunction and the BW. That is, we have been provided neither an explanation for quantum mechanics nor for other features of the BW, let alone a unifying explanation of relativity and the quantum. Talk of macroscopic objects *supervening on* the mass density distribution is no less trivial than merely asserting it's a BW and everything is just "there," again, the real hidden variable here is the entire actual history of the universe, period. And again, we still have not been provided a story about the acausal global constraints, nor a clear non-trivial story about why or how locality is preserved beyond the invocation of counterfactual causal dependencies. As the next section shows, RBW has answers to all these questions with no lacunae. As seen in the next section, RBW *does* provide an "underwriting" story for the acausal global constraints and the probability distribution.

3. ***An RBW Model of QLE.*** By limiting any account of QLE to a story about the interactions of objects or entities in spacetime (such as the intersection of point-particle-worldlines, or an everywhere-continuous process *connecting* two or more worldlines), it is on the face of it difficult to account for IFM given entanglement and preserve locality since, naively, a necessary condition for an "interaction" per particle or *thing* based physics is the "intersection of two or more worldlines." However since the entire spatiotemporal configuration of the IFM in QLE "generated" the entanglement, we can use spacetime symmetries to model the *entire* spacetime configuration of the experiment in a non-trivial way so as to predict and explain the EPR correlations in QLE (Stuckey *et al.*, 2008).

Since spatiotemporal relations provide the ontological basis for our geometric interpretation of quantum theory, spacetime symmetries provide the explanation (*qua* mathematical description) of quantum phenomena. That is, the distribution of clicks at the detectors reflects the spatiotemporal relationships between the source, beam splitters, mirrors, and detectors as described by the spacetime symmetry group – spatial translations and reflections in this case. The relevant 2D irreducible Resentations (irreps) for 1-dimensional translations and reflections are:

$$T(a) = \begin{pmatrix} e^{-ika} & 0 \\ 0 & e^{ika} \end{pmatrix} \quad \text{and} \quad S(a) = \begin{pmatrix} 0 & e^{-2ika} \\ e^{2ika} & 0 \end{pmatrix}$$

respectively, in the eigenbasis of T, and *these are the fundamental elements of our geometric description of the MZI in the Heisenberg formalism*. In Stuckey *et al.* (2008) we show the density operator of an experimental configuration can be obtained from the "past, present and future" of the entire spatiotemporal configuration *a la* the spacetime symmetries of the experimental set-up: from the initiation of the experiment to its outcomes (as is clear also, for example, in our path-integral formalism). Since, with this ontology of spatiotemporal relations, the matter-geometry dualism has been collapsed per ontological structural realism such that both "object" and "influence" reduce to *spacetime relations* for the purposes of modeling QLE. In our path integral approach, for example, "entanglement" is seen as correlated outcomes in an "all at once" description of the experiment per the symmetries of the action (Stuckey and Silberstein, 2008). Note there is no mention of photon interference here. We are simply describing the distribution of events (clicks) in spacetime (spatial projection, rest frame of MZI) using the fundamental ingredients in this type of explanation, i.e., spacetime symmetries (spatial translations and reflections in the MZI, rotations in the case of spin measurements). What it means to "explain" a phenomenon in this context is to provide the distribution of spacetime events per the spacetime symmetries relevant to the experimental configuration, so RBW constitutes an *acausal* and *adynamical* characterization and global (kinematical or geometrical) explanation of entanglement.

3.1 Relata and Relations. Since RBW is predicated upon the claim that dynamic entities, e.g., particles and fields, are not ontologically fundamental, it is incumbent upon us to provide, if only heuristically, a means by which dynamic entities might be constructed via relations. We have done so elsewhere (Stuckey and Silberstein, 2008) using a discrete path integral formalism over graphs based on the self-consistent definition of trans-temporal objects, space and time. In summary, self-consistency principle → discrete action → symmetry amplitude ("discrete transition amplitude" in the parlance of quantum field theory). This provides conceptually, if not analytically, a basis for the RBW ontology and methodology, enumerated as follows:

1. Each piece of equipment in an experimental set-up results from a large number of spatiotemporally dense relations, so low-intensity sources and high-sensitivity detectors must be used to probe the realm of rarefied relations described by QM.

2. A "detector click" is a subset of the detector that also results from a large number of spatiotemporally dense relations; we infer the existence of a rarified set of relations between the source and the detector at the beginning of the click's worldline.

3. It is this inferred, rarified set of relations for which we compute the symmetry amplitude.

4. A symmetry amplitude must be computed for each of all possible click locations (experimental outcomes) and this calculation must include (tacitly if not explicitly) all relevant information concerning the spacetime relationships (e.g., distances and angles) and property-defining relations (e.g., degree of reflectivity) for the experimental equipment per the action.

5. The relative probability of any particular experimental outcome can then be determined by squaring the symmetry amplitude for each configuration (which includes the outcomes) and normalizing over all configurations.

3.2 QLE and Blockworld. Our analysis of QLE shows the explanatory necessity of the reality of all events—in this case the reality of all phases of the QLE experiment. We can provide an illustrative, though qualitative, summary by referring to three phases of QLE in Figs. 5 and 6. Again, in the first phase the boxes Z_1+, Z_1-, Z_2+, and Z_2 – are prepared (turned into "silent" detectors of sorts), in the second phase the four boxes are placed in the MZI per Fig. 2 and a D click is obtained, and in the third phase the boxes are subjected to EPR spin measurements (Fig. 4).

We are not describing "photons" moving through the MZI or "atoms" whose spin-states are being measured. According to our ontology, clicks are evidence not of an impinging particle-in-motion, but of rarified *relations* which are a subset of the dense set comprising the equipment of the experiment. If a Z measurement is made on either pair of boxes in phase 3, an inference can be made *a posteriori* as to which box acted as a "silent" detector in phase 2 (Fig. 6). If Γ and/or Δ measurements are done on each pair (Fig. 5), then there is *no fact of the matter* concerning the detector status of the original boxes. This is not simply a function of ignorance because if it was possible to identify the "silent" detectors before the Γ and/or Δ measurements were made, the Bell assumptions would be met and the resulting spin measurements would satisfy the Bell inequality. Therefore, *that none of the four boxes can be identified as a detector in phase 2 without a Z measurement in phase 3 is an ontological, not epistemological, fact* and points to the necessity of, if you will, an "all at once" BW explanation. Notice that what obtains in phase 3 "determines" what obtains in phase 2, so we have a true "delayed-choice" experiment. For example, suppose box Z_2 – is probed in phase 3 (Z measurement) and an event is registered (an "atom resides therein," Fig. 6). Then, the Z_2 – and Z_1 – boxes are understood during phase 3 to be detectors in phase 2. However, nothing in the blockworld has "changed" – the beings in phase 2 have not "become aware" of which boxes are detectors. Neither has anything about the boxes in phase 2 "changed." According to our view, the various possible spatiotemporal distributions of events are each determined by QM *as a whole throughout space and time.*

Conclusion. In Figs. 5 & 6, one can chart implications from phase 1 to phase 3 then back to phase 2, since the order in which we chart implications in a spacetime diagram is meaningless (meta-temporal) to the blockworld inhabitants. In point of fact, the collective characteristics in all three phases of QLE are acausally and globally (without attention to any common-cause principle) determined by the spacetime symmetries of the *entire actual history* of the experimental set-up; hence, the *nontrivial* explanatory *necessity* of the blockworld. What *determines* the outcomes in QLE is not given in terms of influences or causes (in any sense of the word). In this way we resolve the quantum liar paradox locally with RBW by showing how "the paradox" is not only *consistent* with a blockworld structure, but, if locality is to be preserved, actually demands an adynamical interpretation such as ours over interpretations involving dynamical entities and their histories whether forwards or backwards in time. It is the *spatiotemporal configuration of QLE as a spacetime whole and its spacetime symmetries* that determine the outcomes and not *constructive (a la Einstein) entities with dynamical histories*. As far as we know, RBW is the only fully developed truly acausal and local account of QM consistent with SR that explains quantum entanglement and resolves the measurement problem. The key to all this is taking seriously the idea that the deepest story underneath QM is an adynamical one.

RBW embraces fundamentally a realism of structure, not trans-temporal *entities* or *things* and, accordingly, adopts a form of *structural explanation* that is acausal and adynamical in nature. RBW is also fundamentally atemporal, in that the reality of all events plays an *essential* explanatory role. It is sometimes pointed out that structural explanation is most clearly understood by considering examples from SR, examples such as the well-known relativistic phenomena of length contraction and time dilation. Viewed as a "principle" theory, following Einstein's famous remarks, SR introduces, as Jeffrey Bub put it, "abstract structural constraints that events are held to satisfy" (as cited in Hughes, 1989). Regarding the phenomenon of length contraction, to explain is to, as Hughes put it,

> [sketch] the models of space-time which special relativity provides and [to show] that in these models, for a certain family of pairs of events [say, the events that constitute the ends of a moving rod], not only is

> their spatial separation *x* proportional to their temporal separation *t*, but the quantity *x*/*t* is invariant across [inertial] coordinate systems; further for all such pairs, *x*/*t* always has the same value. (Hughes, 1989, p. 257).

The crucial point here is that *causality does not figure into the analysis of length contraction*, yet explanation can nonetheless be had. As Hughes says,

> This [explanation] makes no appeal to causality; rather it points out structural features of the models special relativity provides. It is, in fact, an example of structural explanation. (*ibid*, p. 257).

Hughes thinks that "explanation comes at many levels," and that, at the "foundational level" to explain is simply to show that certain abstract structural features must be satisfied by any model of the theory in question (*ibid.*). But – and this is where Hughes' embrace of structural explanation is left wanting – what sort of *ontology* might we supply for SR such that causal or dynamical explanations are obviously not fundamental, unhelpful, irrelevant or, as he says, "misleading?" We are left wanting a *realistic* explanation of the phenomenon of length contraction, in terms of a *physical ontology* whose behavior is determined by dynamical laws of motion—a "constructive" account. It is the physical ontology behaving in accordance with the dynamical laws of nature that we are "designed" to find illuminating or explanatory; not the instantiation of abstract mathematical structures. Structural explanation has some precedent in the interpretation of quantum theory (see, for example, the discussion in Hughes 1989, p. 256 ff.), but again, it's often plagued by the fact of an unclear or absent ontology, and so it's open to the objection that what structural "explanations" provide are just mathematical descriptions parading as explanations. We hope our analysis of QLE *a la* RBW will go some way towards loosening the grip of "constructive," dynamical, temporal and causal biases in fundamental physics.

Figure 18 (Fig. 1, App. 2)

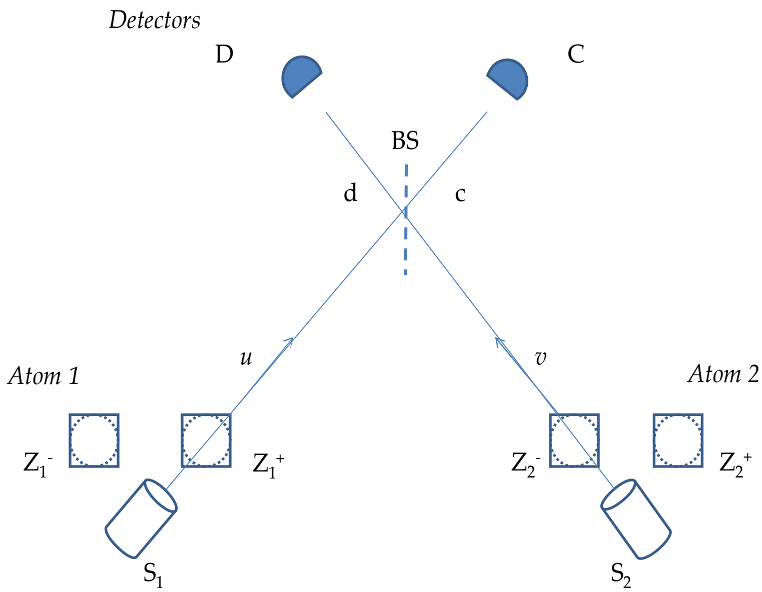

Fig. 1: Basic Quantum Liar set-up, with spatially separated photon sources
(based on fig. 17.11 of Elitzur & Dolev 2005)

Figure 19 (Fig. 2, App. 2)

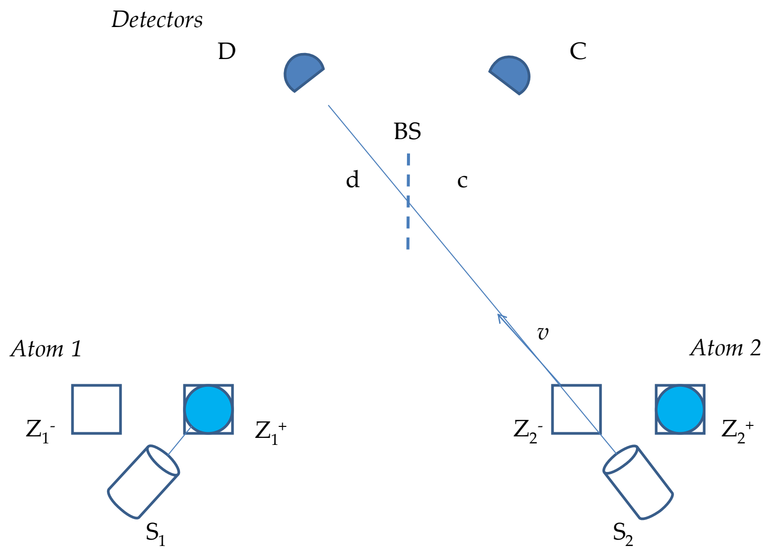

Fig. 2: entanglement between atoms, yet no causal connection in past/future
(based on fig. 17.12 of Elitzur & Dolev 2005)

Figure 20 (Fig. 3, App. 2)

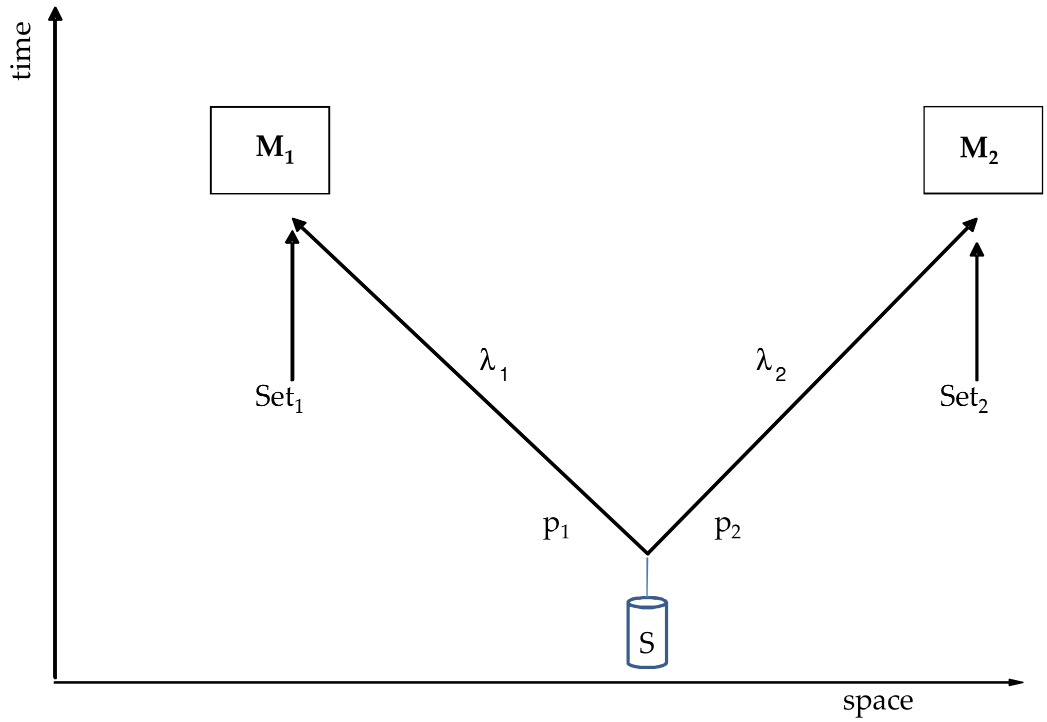

Fig. 3: Schematic spacetime diagram of basic EPR experiment

Figure 21 (Fig. 4, App. 2)

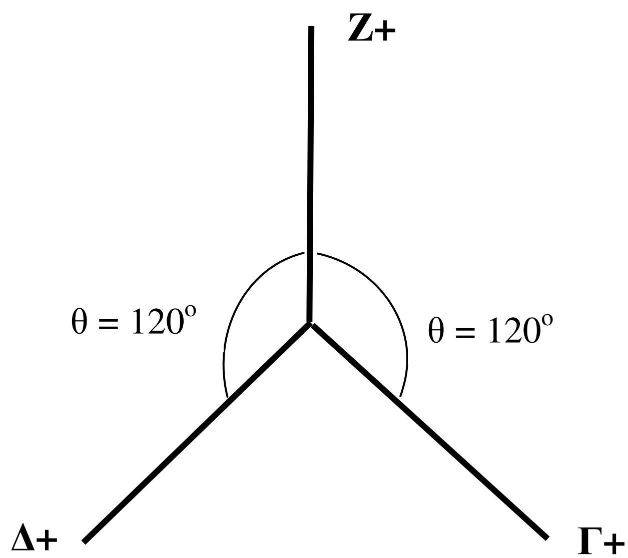

Fig. 4: Stern-Gerlach angles for spin measurements in the Y-Z plane.

Figure 22 (Fig. 5, App. 2)

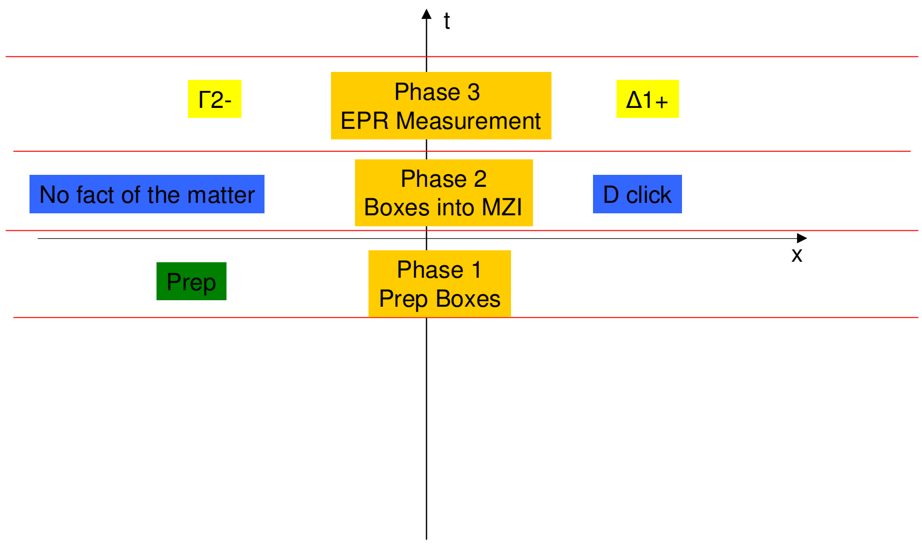

Fig. 5: Experimental sequence consistent with no spin measurements in the Z direction after a D click.

Figure 23 (Fig. 6, App. 2)

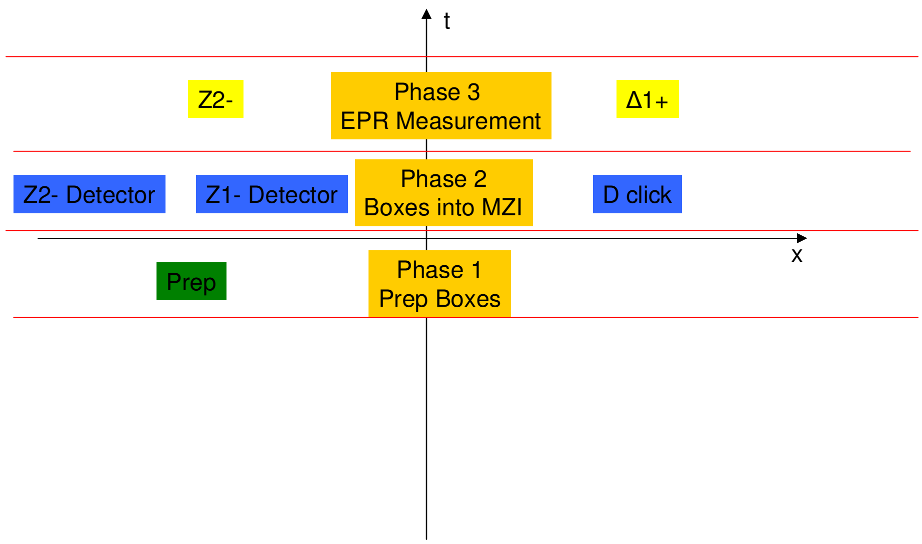

Fig. 6: Experimental sequence consistent with a spin measurement in the Z direction after a D click.

(Source materials for appendix 2)

Aharonov, Y. Bergmann, P. and Lebowitz, J. (1964). "Time symmetry in the quantum process of measurement." *Physical Review*, **134B**, 1410 – 1416.

Aharonov, Y. Botero, A. Popescu, S. Reznik, B. and Tollaksen, J. (2002). "Revisiting Hardy's paradox: counterfactual statements, real measurements, entanglement and weak values." *Physics Letters A*, **301**, 130 – 138.

Barrett, J. A. (2005). "Relativistic quantum mechanics through frame-dependent constructions." *Philosophy of Science,* **72** (December), 802-813.

Bohr, A. and Ulfbeck, O. (1995). "Primary manifestation of symmetry. Origin of quantal indeterminacy." *Reviews of Modern Physics*, **67**: 1 – 35.

Bohr, A., Mottelson, B.R. and Ulfbeck, O. (2004). "The principle underlying quantum mechanics." *Foundations of Physics*, **34**, 405 – 417.

Brown, H.R. & Holland, P.R. (1999). "The Galilean covariance of quantum mechanics in the case of external fields." *American Journal of Physics*, **67**, 204 – 214.

Butterfield, J. (1992). "Bell's theorem: what it takes." *British Journal for the Philosophy of Science* **43**, 41-83.

Callender, C. (1998). "The view from no-when (review of *Time's arrow and archimedes' point: new directions for the physics of time*)." *British Journal for the Philosophy of Science*, **49**, 135 – 159.

Cramer, J. (1980). "Generalized absorber theory and the EPR paradox." *Physical Review D, 22*, 362 – 376.

Cramer, J. (1986). "The transactional interpretation of quantum mechanics." *Review of Modern Physics,* **58**, 647 – 687.

Dainton, B. (2001). *Time and space.* McGill-Queen's University Press: Montréal.

Dickson, W. M. (1998). *Quantum chance and non-locality*. Cambridge: Cambridge University Press.

Einstein, A. Podolsky, B. and Rosen, N. (1935). "Can quantum-mechanical description of physical reality be considered complete?" *Physical Review*, **47**, 777 – 780.

Elitzur, A.C. and Dolev, S. (2005). Quantum phenomena within a new theory of time. In A. Elitzur, S. Dolev and N. Kolenda (eds.), *Quo vadis quantum mechanics?* Berlin: Springer Verlag, 325 – 349.

Elitzur, A.C. and Vaidman, L. (1993). "Quantum mechanical interaction-free measurements." *Foundations of Physics*, **23**, 987 – 997.

Geroch, R. (1978). General relativity from A to B. Chicago: Chicago University Press.

Hardy, L. (1992). "On the existence of empty waves in quantum theory." *Physics Letters A*, **167**, 11 – 16.

Hardy, L. (1993). "Nonlocality for two particles without inequalities for almost all entangled states." *Physical Review Letters*, **71**, 1665 – 1668.

Hardy, L. (1994). "Nonlocality of a single photon revisited." *Physical Review Letters*, **73**, 2279 – 2283.

Hughes, R. (1989). *The structure and interpretation of quantum mechanics*. Harvard University Press.

Kastner, R. (1999). “Time-symmetrised quantum theory, counterfactuals, and ‘advanced action’.” *Studies in the History and Philosophy of Modern Physics,* **30** (2), 237 – 259.

Lewis, P. (2006). “Conspiracy theories of quantum mechanics.” *British Journal of the Philosophy of Science*, **57**, 359 – 381.

Lewis, P. (2007). “Towards a local hidden variable theory.” *Foundations of Physics*, **37**, 461 – 1469.

Mermin, D. (1981). “Bringing home the atomic world: Quantum mysteries for anybody.” *American Journal of Physics*, **49** (10), 940 – 943.

Mermin, D. (1998). “What is quantum mechanics trying to tell us?” *American Journal of Physics*, **66**, 753-67.

Price, H. (1996) *Time’s arrow and archimede’s point* (Oxford: University Press, Oxford), p. 260.

Price, H. (2007). Causal perspectivalism. In Price, H. and Cory, R. (eds.), *Causation, physics, and the constitution of reality: Russell's republic revisited,* Oxford University Press, 250-292.

Saunders, S. (1993). “Decoherence, relative states and evolutionary adaptation.” *Foundations of Physics*, **23**, 1553-85.

Sharp, W. and Shanks, N. (1993). “The rise and fall of time-symmetrized quantum mechanics.” *Philosophy of Science,* **60**, 488 – 499.

Stuckey, W.M. and Silberstein, M. and Cifone, M. (2008a). “Reconciling spacetime and the quantum: relational blockworld and the quantum liar paradox.” *Foundations of Physics*, **38** (4), 348 – 383.

Stuckey, W. M. and Silberstein, M. (2008).”Unification per the relational blockworld.”
quant-ph/0712.2778.

Wharton, K.B. (2007). “Time-symmetric quantum mechanics.” *Foundations of Physics*, **37** (1), 159 – 168.

Bibliography

Aharonov, Y.; Bergmann, P. G. and Lebowitz, J. L. (1964), "Time Symmetry in Quantum Process of Measurement", *Physical Review B* 134 (6B): 1410.

Beaney, M. (2009), "Analysis" in *Stanford Encyclopedia of Philosophy*.

Bell, John S. (1987), *Speakable and Unspeakable in Quantum Mechanics*. Cambridge: Cambridge University Press.

Bohm, David (1951), *Quantum Theory*. New York: Dover.

Brown, Harvey (2005), *Physical Relativity: Space-time Structure from a Dynamical Perspective*. Oxford: Oxford University Press.

Bub, J. (2005), "Quantum Mechanics Is About Quantum Information", *Foundations of Physics* 34(4): 541—560.)

------------------, "Why The Quantum", *Studies in History and Philosophy of Modern Physics* 35: 241—266.

Burtt, E. (2003[1932]), *The Metaphysical Foundations of Modern Science*. New York: Dover.

Callender, Craig (1998), "The View From No When", review of Huw Price's *Time's Arrow and Archimedes' Point: New Directions for the Physics of Time, British Journal for the Philosophy of Science* 49 (1): pp. 135 – 159.

Clifton, R., Bub, J., and Halvorson, H. (2003), "Characterizing Quantum Theory in Terms of Information-Theoretic Constraints", e-Print: arXiv.org quant-ph/0211089.

Cramer, John G. (1986), "The transactional interpretation of quantum mechanics", *Reviews of Modern Physics* 58: 647–687.

Cushing, J. T. and McMullin, E. (eds.) (1989), *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem.* Notre Dame: University of Norte Dame Press.

Devitt, M. (2002) "Scientific Realism" (manuscript).

Dijksterhuis, E. J. (1961), *The Mechanization of the World Picture: Pythagoras to Newton*. Princeton: Princeton University Press.

Duvenhage, R. (2002), "The Nature of Information in Quantum Mechanics", e-Print: arXiv.org quant-ph/0203070

Duwell, A. (2003), "Quantum Information Does Not Exist", *Studies in History and Philosophy of Modern Physics*: 34(3): 479—499.

Fine, Arthur (1989), "Do Correlations Need to be Explained?", in James T. Cushing and Ernan McMullin (eds.), *Philosophical Consequences of Quantum Theory*. Notre Dame: University of Notre Dame Press, 175–194.

Frisch, M. (2005), "Mechanisms, Principles, and Lorentz's Cautious Realism", *Studies in the History and Philosophy of Modern Physics* 34 (4): 659—679.

Fuchs, C. (2002b), "Quantum Mechanics as Quantum Information (and only a littlemore)", e-Print: arXiv.org quant-ph/0205039.

Hagar, (2003), "A Philosopher Looks at Quantum Information Theory", *Philosophy of Science* 70: 752—775.

Heidegger, Martin ([1927]2008), [*Sein und Zeit*] *Being and Time*. Trans. by John Maquarrie and Edward Robinson (orig. pub. 1962). New York: Harper Perennial Modern Classics.
Hoefer, Carl (2003), "Causal Determinism", in *Stanford Encyclopedia of Philosophy*.
Horodecki, R., Horodecki, M., and Horodecki, P. (2003), "Quantum Information Isomorphism: Beyond the Dilemma of Scylla of Ontology and Charybdis of Instrumentalism", e-Print: arXiv.org quant-ph/0305024.
Jozsa, R. (1998), "Quantum Information and Its Properties", *in* Lo, H., Popescu, S., and Spiller, T., *Introduction to Quantum Computation and Information*, pp. 49-75. Singapore: World Scientific.
Ladyman, J.; Ross, D.; Spurrett, D. and Collier, J. (2007), *Everything Must Go: Metaphysics Naturalized*. Oxford: Oxford University Press.
Lewis, Peter J. (2005), "Conspiracy Theories of Quantum Mechanics", *British Journal for the Philosophy of Science* 57(2): 359—381.
Maudlin, Tim (2007), *The Metaphysics Within Physics*. New York: Oxford University Press.
---------------- (1994), *Quantum Non-Locality & Relativity*. Oxford: Blackwell.
McMullin, E. "The Explanation of Distant Action: Historical Notes" *in* Cushing, *et. al.*, pp. 272-302.
Newton, Isaac (c. 1685/2004), *De Gravitatione* in *Isaac Newton: Philosophical Writings*. Cambridge: Cambridge University Press.
Nielsen, M. A. (2000), "Introduction to Quantum Theory", e-Print: arXiv.org quant- ph/0011064.
Pieper, J. (1960), *Scholasticism*. Chicago: St. Augustine's Press.
Price, Huw (1996), *Time's Arrow and Archimedes Point*, Oxford University Press, Oxford.
------------- (2001), "Backward causation, hidden variables and the meaning of completeness", *Pramana – Journal of Physics* 55 (2 – 3): 199 – 209.
Polanyi, M. (1974), *Personal Knowledge: Towards A Post-Critical Philosophy*. Chicago: University of Chicago Press.
Quine, W.V.O. (1999), *From A Logical Point of View*. Boston: Harvard University Press.
Reichenbach, H. (1957), *The Philosophy of Space and Time*. New York: Dover.
Rovelli, Carlo (1996), "Relational Quantum Mechanics", *International Journal of Theoretical Physics* 35 (8): 1637 – 1678.
Salmon, W. (1984), *Scientific Explanation and the Causal Structure of the World*. Princeton: Princeton University Press.
Sellars, W. (1963), *Science, Perception and Reality*. New York: The Humanities Press.
Shannon, C. E. (1948), "A Mathematical Theory of Communication", e-Print. Originally in: *The Bell System Technical Journal*, 27: 379-423, 623-656.
Smolin, L. (2007) *The Trouble With Physics*. New York: Mariner.
Tillich, P. (1967), *A History of Christian Thought*. New York: Touchstone.
Timpson, C. G. (2000), "Information and the Turing Principle: Some Philosophical Considerations" (B.Phil thesis, University of Oxford).

Van Fraassen, B. C. (1989), “The Charybdis of Realism: Epistemological Implications of Bell’s Inequality” *in* Cushing, *et. al.,* pp. 97-113.

Worrall, J. (1989), “Structural Realism: The Best of Both Worlds?”, *Dialectica* 43 (1-2): 99—124.