Intrinsicality and Entanglement

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Abstract

I explore the relationship between a prominent analysis of intrinsic properties, due to Langton and Lewis, and the phenomenon of quantum entanglement. As I argue, the analysis faces a puzzle. The full analysis classifies certain properties of entangled particles as intrinsic. But when combined with an extremely plausible assumption about duplication, the main part of the analysis classifies those properties as non-intrinsic instead. I conclude that much of Lewis's metaphysics is in trouble: Lewis based many of his metaphysical views—his thesis of Humean supervenience, for instance, and his account of recombination—on an analysis of intrinsicality which does not sit well with quantum phenomena.

1 Introduction

Lewis gives the following intuitive characterization of intrinsic properties: "[a] thing has its intrinsic properties in virtue of the way that thing itself, and nothing else, is. . . The intrinsic properties of something depend only on that thing; whereas the [non-intrinsic] properties of something may depend, wholly or partly, on something else" (1983a, p. 197). By way of illustration, consider a ball owned by a little girl. The property *is 100 grams in mass* has only to do with the way the ball itself is, since the ball's instantiation of it does not depend on what any other object is like. The property *is 100 grams in mass* is, therefore, an intrinsic property of the ball. The ball also instantiates the non-intrinsic property[1] *belongs to a little girl*. This property is non-intrinsic because it depends on other objects besides the ball: the existence of the girl, institutions of ownership, and so on.

The intrinsic/non-intrinsic distinction is important to philosophy in a number of ways. Moore (1903) used it to distinguish things that are good in themselves from things that are good insofar as they are a means to something else. Geach (1969) and Humberstone (1996) used it to distinguish real from so-called 'mere Cambridge' change. Kim (1982) used it to defend a restricted version of the claim that psychological states supervene upon physical states. Lewis (1986a) used it to argue for perdurantism.

Intrinsicality also features in discussions of the world's fundamental physics. According to Lewis's thesis of Humean supervenience, the world consists of spacetime points which instantiate intrinsic properties (Lewis, 1986b, pp. ix-x; Loewer, 2004, p. 180). Standard versions of the 'best system' account of lawhood assume that the properties mentioned in fundamental physical theories are intrinsic (Lewis, 1983b, pp. 357-68). Physical theories which posit only intrinsic properties are preferable to physical theories which posit non-intrinsic properties (Ney, 2010). And non-intrinsic explanations of physical phenomena – which cite properties that depend on objects 'outside' of the phenomena to be explained – are less illuminating than intrinsic explanations – which do not (Field, 1980, pp. 43-46).

Langton and Lewis (1998) have proposed one of the most prominent and influential analyses of intrinsicality to date.[2] As will be explained later, according to Langton and Lewis, intrinsic properties are properties that never differ between duplicates. Their analysis has been used in many ways: for instance, to characterize spacetime points (Schrenk, 2014), to formulate counterexamples to recombination principles (Kleinschmidt, 2015), and to criticize

[1]By 'non-intrinsic', I mean not intrinsic. So no property can be both intrinsic and non-intrinsic, on pain of violating the law of non-contradiction.

[2]See (Marshall, 2012, p. 531) for more discussion of the influence of Langton and Lewis's analysis.

counterpart theory (De, 2016).

Obviously, analyses of intrinsicality should not classify one and the same property as intrinsic and non-intrinsic both. But as I will argue, Langton and Lewis's analysis, in conjunction with a very natural assumption about what objects are duplicates of each other, does exactly that for a certain quantum property that features in entangled systems. The full version of Langton and Lewis's analysis classifies that property as intrinsic. But when combined with the assumption about duplication—an assumption which is extremely hard to deny without directly contradicting Langton and Lewis's analysis—the main part of the analysis classifies that property as non-intrinsic. So the analysis is, in a sense, incongruous: it faces a puzzle when used to classify certain quantum properties.[3]

The issues I raise for Langton and Lewis's analysis are different from issues raised elsewhere in the literature. The puzzle is not that Langton and Lewis's analysis yields intuitively incorrect classifications of certain properties. It is already well-known that their analysis incorrectly classifies non-qualitative properties[4] as non-intrinsic (Marshall, 2016b, p. 242), for example. In the case of my puzzle, the very same property gets classified as intrinsic by one part of Langton and Lewis's analysis, and non-intrinsic by another. And since the property that generates the puzzle is qualitative, the puzzle cannot be avoided by restricting the analysis to qualitative properties only.

Here is another unique feature of the puzzle: a version of it applies to other analyses of intrinsicality that use the notion of duplication. In order to keep the forthcoming discussion concrete, I focus on the analysis due to Langton and Lewis. But a similar puzzle arises for

[3]There is not much literature on the relationship between quantum mechanics and specific analyses of intrinsicality. For discussions of intrinsicality at the quantum level, see Esfeld (2014), Miller (2014), and Ney (2010). These authors' principal focus, however, is on the metaphysics of quantum mechanics, not the metaphysics of intrinsicality. So they do not discuss specific analyses of intrinsic properties, such as Langton and Lewis's analysis.

[4]Qualitative properties are properties that can be expressed without mentioning any specific individuals. The property *has a nose* is qualitative, for example, while the property *has Obama's nose* is not.

an earlier analysis that Lewis proposed (1986a). And a similar puzzle will probably arise for other analyses of intrinsicality that rely on duplication. So one upshot of this paper is that analyses of intrinsicality should probably not rely on duplication at all. Perhaps hyperintensional analyses are the way to go (Bader, 2013; Marshall, 2016a).

The puzzle reveals a deep problem that underlies much of Lewis's metaphysics. Lewis uses intrinsicality in many places: his account of Humean supervenience, his account of recombination, his account of duplication, and so on. It is well known, of course, that Lewis's metaphysics does not always combine easily with quantum mechanics: his version of Humean supervenience does not respect the non-separability of quantum states, for instance (Maudlin, 2007). But as my puzzle shows, the conflict between Lewis's metaphysics and quantum mechanics runs even deeper. Lewis based much of his metaphysics on an account of intrinsicality to which quantum phenomena do not conform.

I proceed as follows. In §2, I present Langton and Lewis's analysis of intrinsicality. In §3, I explain the basics of quantum entanglement. In §4, I present the puzzle. In §5, I show that Langton and Lewis's analysis faces even more basic issues on standard interpretations of quantum mechanics.

Before continuing, it is worth heading off a potential issue. At first, it might appear that the puzzle depends on actual-world details of the quantum property in question. But that is not so. The actual facts about that property—whether or not it is exemplified at the *actual* world, for instance—are irrelevant. For like every analysis of intrinsicality, Langton and Lewis's analysis seeks to classify *possible* properties, not just actual ones. So long as the property is merely possible—and it certainly is, on many different interpretations of quantum mechanics—the puzzle holds. In particular, the puzzle holds independently of what the best theory of non-relativistic quantum mechanics ultimately turns out to be.

2 Langton and Lewis's analysis of intrinsicality

Langton and Lewis advocate a two-part analysis (1998, pp. 334-37). First, they analyze what they call basic intrinsic properties. Second, they use basic intrinsic properties to analyze intrinsicality, in the way described below.

> <u>Intrinsic properties</u>
>
> Property P is *intrinsic* if and only if for any duplicates x and x', either both x and x' instantiate P or neither x nor x' instantiate P.

Duplication is analyzed in terms of basic intrinsic properties.

> <u>Duplication</u>
>
> Object x' is a *duplicate* of object x if and only if x and x' have exactly the same basic intrinsic properties.

Finally, basic intrinsic properties are analyzed in terms of three conditions.

> <u>Basic intrinsic properties</u>
>
> Property P is *basic intrinsic* if and only if
>
> (i) P is independent of accompaniment,
>
> (ii) P is not a disjunctive property, and
>
> (iii) P is not the negation of a disjunctive property.

The remainder of this section concerns these conditions.

First, condition (i). Independence from accompaniment is defined in terms of two interrelated notions: accompanied objects, and lonely objects.

> <u>Accompaniment</u>
>
> Object x is 'accompanied' $=_{df}$ x coexists with a contingent object that is wholly distinct from it.

The other object must be contingent because if coexistence with a necessary object were sufficient for being accompanied, and if necessary objects exist, then every object x would be accompanied automatically. The other object must be wholly distinct from x because otherwise, x would be accompanied even if the only other objects were, for instance, parts of it.

Loneliness

Object x is 'lonely' $=_{df}$ x is not accompanied.

Finally, here is the definition of independence from accompaniment.

Independent of accompaniment

Property P is 'independent of accompaniment' $=_{df}$ the following four conditions hold.

(1) It is possible for a lonely object to instantiate P.

(2) It is possible for a lonely object not to instantiate P.

(3) It is possible for an accompanied object to instantiate P.

(4) It is possible for an accompanied object not to instantiate P.

For example, the property *is red* is independent of accompaniment because lonely red objects, lonely non-red objects, accompanied red objects, and accompanied non-red objects, are all possible. The property *is one meter away from a red object*, however, is not independent of accompaniment. A lonely object cannot instantiate it.

It might seem that a satisfactory analysis of intrinsicality can be obtained by taking the basic intrinsic properties to be all and only those properties that are independent of accompaniment. One might wonder, in other words, whether conditions (ii) and (iii) are needed. If not, then basic intrinsic properties can be analyzed in terms of independence from accompaniment, duplication can be analyzed in terms of basic intrinsic properties, and intrinsicality can be analyzed in terms of duplication.

But as Langton and Lewis point out, such an analysis would be problematic. For example, the property *is cubical and lonely, or is non-cubical and accompanied* is intuitively non-intrinsic, since its exemplification clearly depends on how things are with the rest of the world. But it is independent of accompaniment: lonely cubes instantiate it, lonely spheres do not, accompanied spheres instantiate it, and accompanied cubes do not. Similarly, the property *is the only red thing*—which is the negation of *is either non-red or accompanied by a red thing*—is independent of accompaniment. Lonely red things have it, lonely non-red things do not, red things accompanied only by non-red things have it, and red things accompanied by red things do not. But it too is intuitively non-intrinsic (Vallentyne, 1997, p. 211).

Note that in both examples, the problematic properties make crucial use of disjunctions. Conditions (ii) and (iii) are required, therefore, in order to deal with the problems that disjunctions create. Basic intrinsic properties are independent of accompaniment, but also neither disjunctive properties – like the property in the first example – nor negations of disjunctive properties – like the property in the second. It follows that according to Langton and Lewis's analysis, neither of the above properties are basic intrinsic.

Disjunctive properties are defined as follows.[5]

<u>Disjunctive</u>

Property P is 'disjunctive' $=_{df}$ P can be expressed by a predicate in disjunctive normal form, where each disjunct expresses a property that is more natural than P.[6]

Langton and Lewis remain neutral as to the account of naturalness used here (1998, pp. 335-36). Taking naturalness to be primitive, or derived from scientific theorizing, or derived from an ontology of sparse universals, would all be acceptable.

Some intuitively intrinsic properties are not basic intrinsic: that is why Langton and Lewis do not stop their analysis of intrinsicality with their analysis of basic intrinsic properties. For instance, consider the intuitively intrinsic property *is either 100 grams in mass or 200 grams in mass*; express this property by 'O'. To see that O is intrinsic, note that any two duplicates x and y either both have the same mass or both lack the same mass (since for any specific mass, the property of having that mass is basic intrinsic). So any such x and y either both have O or both lack O. To see that O is not basic intrinsic, note that O is

[5] The definition presented here includes improvements that Lewis advocated later (2001, p. 387).

[6] In §4, I discuss naturalness in more detail.

disjunctive. For O can be expressed by a predicate in disjunctive normal form, where each disjunct is more natural than O: in particular, O can be expressed by '$M_1 \vee M_2$', where 'M_1' expresses the property *is 100 grams in mass* and 'M_2' expresses the property *is 200 grams in mass*.

This completes the summary of Langton and Lewis's analysis of intrinsic properties. Basic intrinsic properties are independent of accompaniment, not disjunctive, and not the negation of disjunctive properties. Duplicates are objects that share their basic intrinsic properties. And intrinsic properties are properties that never differ between duplicates.

3 Quantum entanglement

The quantum property that makes trouble for Langton and Lewis's analysis is called 'spin'. Other quantum properties make trouble for Langton and Lewis too: any property which is as central to quantum theory as spin is, but which can become entangled, is a threat. I focus on spin because the puzzle it generates is particularly perspicuous and general.

Roughly put, a particle's spin comprises some of its total angular momentum.[7] The term 'spin' derives from an analogy between the angular momentum of particles and the angular momentum of planets. While part of a planet's total angular momentum consists in its orbital motion, part also consists in its rotation about its own axis. Similarly, the spin of a particle—an electron, say—is the portion of its angular momentum that does not derive from orbital motion around an atomic nucleus.

Spin properties consist of a magnitude and a direction along which the spin is oriented. For any electron e, its magnitude of spin is $\frac{1}{2}$. And for any given direction, the spin of e—if measured along that direction—will always be found to be either 'up' (pointing one way along the directional line) or 'down' (pointing the other way). So let $\hat{x}$ be some fixed direction in

[7]Following standard practice, I assume that spin is not produced by any underlying mechanism. See (Ohanian, 1986) and (Sebens, 2019), however, for possible mechanical origins for spin.

physical space, let U be the property *has $\hat{x}$-spin up*, and let D be the property *has $\hat{x}$-spin down*. Note that U and D agree on the magnitude of spin: that magnitude is $\frac{1}{2}$ in both cases. They differ only with respect to orientation.[8]

Like many quantum properties, U and D can enter into what are called 'superpositions'. Very roughly, when a particle is in a superposition spin state, its spin is a mixture of U and D. More precisely, when a particle is in a superposition spin state, there is a probability distribution describing the chance that upon measurement, the particle will be found to have U (or D). For example, the spin of electron e could be in the following superposition: if the spin of e is measured, there is a 50% chance that e will be found to have U and a 50% chance that e will be found to have D. So suppose e is shot through a spin-measuring device $\mathcal{M}$ that has two exits: an '$\hat{x}$-spin up' exit and an '$\hat{x}$-spin down' exit. Particles with U always come out the '$\hat{x}$-spin up' exit, and particles with D always come out the '$\hat{x}$-spin down' exit. Particles in a superposition spin state, however, sometimes come out one exit and sometimes come out the other. In particular, if e enters $\mathcal{M}$ then in virtue of e's spin superposition, there is a 50% chance that e will leave through the '$\hat{x}$-spin up' exit and a 50% chance that e will leave through the '$\hat{x}$-spin down' exit.

A 'spin superposition property' is a property that generates this sort of probabilistic behavior. There are many different spin superpositions; continuum many, in fact. For each r between 0 and 100, let 'S_r' express the spin superposition property that corresponds to the

[8] In describing U and D, I made an arbitrary choice: I arbitrarily chose the direction $\hat{x}$, and I described U and D in terms of it. In the literature on gauge theory, the arbitrariness of such choices is sometimes taken to indicate that the corresponding property is not physically real (Healey, 2007). That is not the situation here, however: U and D are physically real properties. Though I described U and D in terms of an arbitrary choice of orientation, I did not define U and D in terms of that choice. *What it is* to exemplify U, and *what it is* to exemplify D, is merely to occupy thus-and-so corresponding vectorial spin states in the relevant Hilbert space. The property of occupying those spin states is physically real: when sent through Stern-Gerlach devices, many particles in the actual world exhibit the statistics corresponding to those spin states. So many particles in the actual world exemplify U and D.

following conditions.

1. If measured, there is an $r\%$ chance that the object exemplifying S_r will be found to have U.
2. If measured, there is a $(100 - r)\%$ chance that the object exemplifying S_r will be found to have D.
3. Measurements of the spin of any other particle do not affect these probabilities for the object exemplifying S_r.

Those familiar with the technical details of quantum mechanics will recognize that U, D, and the S_r are pure spin states of a single particle.[9]

For example, suppose e exemplifies S_{25}. Then if e is measured, there is a 25% chance that e will be found to have U and a 75% chance that e will be found to have D. The superposition spin property mentioned earlier—that if the spin of e is measured, there is a 50% chance that e will be found to have U and a 50% chance that e will be found to have D—is just S_{50}.

In virtue of the third condition, the probabilities for each S_r property do not depend on anything else. In particular, measurements of the spin of another particle do not affect the probability distribution for a particle that has S_r. So for example, suppose e has S_{50}, and suppose some other particle n has S_{25}. And suppose we send n through $\mathcal{M}$. Then regardless of what n is found to have—regardless of whether n leaves through the '$\hat{x}$-spin up' exit or the '$\hat{x}$-spin down' exit—e continues to have S_{50}. If e is sent through $\mathcal{M}$ then there is still a

[9] In order to illustrate—in an intuitive and accessible way—what these S_r properties are like, I have described these properties in terms of probabilities for measurement outcomes. In the full formalism of quantum mechanics, however, the S_r properties are not defined in terms of probabilities. For each r, S_r is the property *is in state* $\sqrt{\frac{r}{100}}\,|U\rangle + \sqrt{1 - \frac{r}{100}}\,|D\rangle$, where this state is a vector in a Hilbert space. So these descriptions are not definitions of the S_r properties. In fact, these descriptions are not metaphysically necessary: worlds with different physical laws will assign different chances to the outcomes of measurements on particles that exemplify S_r. These descriptions are merely nomically necessary: they hold in all worlds with the same quantum mechanical laws as our world.

50% chance that e will be found to have U and a 50% chance that e will be found to have D. The probabilities for e are independent of the outcomes of measurements on n.

There are spin states for which this is not so, however. In cases of quantum entanglement, measurements of one particle's spin can affect the probabilities for another particle's spin. Suppose, for instance, that electron e and positron p are entangled with respect to their spins, so that their joint state is fully characterized by the following three conditions.

1. Measurements of e and p will always find that they have opposite spins.
2. If e is measured first, there is a 50% chance that it will be found to have U and a 50% chance that it will be found to have D.
3. If p is measured first, there is a 50% chance that it will be found to have U and a 50% chance that it will be found to have D.

For an example of what the first condition means, suppose e is measured first. According to the first condition, if e is found to have U, then subsequent measurements of p will definitely find that p has D. And according to the first condition, if e is found to have D, then subsequent measurements of p will definitely find that p has U.

Let '$SE(U, D)$' express the monadic property of being in the state which these three conditions describe.[10] So particle x has $SE(U, D)$ just in case there exists a particle y such that with x substituted for e and y substituted for p, the three conditions above are true. Note that both e and p have $SE(U, D)$.

An imperfect but helpful analogy will clarify what $SE(U, D)$ is like. Imagine two winter hats, one black and one white, which siblings Addie and Ruth love to wear. Each morning, one sibling grabs one hat and one sibling grabs the other. Observations of these two siblings will always find that they have opposite-colored hats; on analogy with the first condition of

[10]The 'SE' stands for 'Spin Entangled'. In order to keep things accessible, I have described the property $SE(U, D)$ in terms of probabilities. The more rigorous definition, in standard quantum terminology, is this: $SE(U, D)$ expresses the property *is such that there exists a y, distinct from x, for which* $\sqrt{\frac{1}{2}}\,|U\rangle_x\,|D\rangle_y - \sqrt{\frac{1}{2}}\,|D\rangle_x\,|U\rangle_y$ *is the spin state of the joint system*, where x is the exemplifying object.

$SE(U, D)$. On any given morning, there is a 50% chance that Addie will be seen wearing the black hat, and there is a 50% chance that Addie will be seen wearing the white hat; on analogy with the second condition of $SE(U, D)$. Similarly, on any given morning, there is a 50% chance that Ruth will be seen wearing the black hat, and there is a 50% chance that Ruth will be seen wearing the white hat; on analogy with the third condition of $SE(U, D)$.[11]

The first condition of $SE(U, D)$ is the heart and soul of quantum entanglement. It expresses the fact that the spins of e and p are anti-correlated. For if the spin of one particle is measured, then the outcome of a subsequent spin measurement of the second particle is always opposite the outcome of the first measurement. The probabilities for e are *not* independent of outcomes of measurements on p. And similarly, the probabilities for p are *not* independent of outcomes of measurements on e. Because of that, if a particle has $SE(U, D)$, then it does not have any S_r. For in virtue of having $SE(U, D)$, it violates the third condition of each S_r property.

4 The puzzle

Recall that Langton and Lewis's analysis proceeds in two steps: in the first, Langton and Lewis analyze basic intrinsic properties; in the second, Langton and Lewis analyze intrinsic properties in general. Though the two steps may seem innocuous, they lead to a puzzle when the properties in question are susceptible to entanglement. The notions employed in the first step can be used to classify U, D, and the S_r as basic intrinsic properties. It follows, of course, that U, D, and the S_r are intrinsic. But the notions employed in the second step, when combined with an independently plausible assumption about duplication, can be used

[11] Remember that this is only an analogy: there are significant differences between the siblings' hat-wearing states and the states of e and p. For instance, on any given morning, before either Addie or Ruth is seen, there is a fact of the matter as to who has the black hat and who has the white hat. But before e and p are measured, there is no fact of the matter as to which particle has U and which particle has D.

to classify at least one of U, D, and the S_r as non-intrinsic. The two parts of Langton and Lewis's analysis give rise to different classifications of spin properties.

The following considerations show that Langton and Lewis's analysis classifies U, D, and the S_r as intrinsic. First, let us see why these properties are independent of accompaniment.[12] Consider U. Many accompanied electrons in the actual world have U and many

[12] In what follows, I assume that there is a fact of the matter as to whether U, D, and the S_r are independent of accompaniment or not (thanks to an anonymous reviewer for pointing this out). Even if one does not share that assumption, however, Langton and Lewis's analysis still runs into problems. For if there is no fact of the matter as to whether U, D, and the S_r are independent of accompaniment, then Langton and Lewis's analysis cannot be used to classify U, D, and the S_r at all. For an example of a view which implies that there is no such fact of the matter—a version of which is defended in (Maudlin, 2007) for the case of color properties of quarks—consider the following: particles only ever exemplify spin properties like U, D, and the S_r relative to paths through spacetime and connections. To see why this implies that there is no such fact of the matter, let us focus on U. By definition, U is independent of accompaniment if and only if (1) it is possible for a lonely object to instantiate U, (2) it is possible for a lonely object to not instantiate U, (3) it is possible for an accompanied object to instantiate U, and (4) it is possible for an accompanied object to not instantiate U. Conditions (3) and (4) are true. So whether or not U is independent of accompaniment comes down to whether or not both (1) and (2) hold. But if particles only ever exemplify spin properties relative to spacetime paths and connections, then there is no fact of the matter as to whether or not both (1) and (2) hold *at once* (so to speak). To see why, note that in order for (1) and (2) to hold or fail to hold, the spins of particles at different possible worlds must be comparable. There must be a fact of the matter, in other words, as to whether (i) a lonely particle x_1 at some world w_1 has U, while (ii) a lonely particle x_2 at some other world w_2 lacks U. But in order for there to be a fact of the matter about that, it must be possible to compare the spin of x_1 at w_1 to the spin of x_2 at w_2. In particular, there must be a fact of the matter about whether x_1 at w_1 has a different spin from x_2 at w_2. According to the view under consideration, comparisons of spin require paths through spacetime and connections: in particular, in order for there to be a fact of the matter as to whether or not two particles have different spins, there must be a spatiotemporal path from one particle to the other. *But there is no spatiotemporal path from x_1 at w_1 to x_2 at w_2, because possible worlds are spatiotemporally disconnected.* So there is no fact of the matter as to whether x_1 and x_2 have different spins. And so there is no fact of the matter as to whether it is possible for a lonely object to instantiate U and also for a lonely object to not instantiate U. Therefore, there is no fact

lack U. It is possible for a lonely electron to have U, and it is possible for a lonely electron to lack U.[13] Similarly for D, and for the S_r. So U, D, and each S_r are independent of accompaniment.

Now for naturalness. There are at least four reasons for thinking that U, D, and the S_r are extremely natural. First, consider an account of naturalness mentioned—though not endorsed—by Lewis: the 'vegetarian conception' (Taylor, 1993, p. 88), according to which natural properties are properties that play a "central and fundamental classificatory role within regimented physics" (Lewis, 2001, p. 382). Plausibly, U, D, and the S_r play a central and fundamental classificatory role in quantum theory, since they help to classify spin states. In particular, U, D, and the S_r play a classificatory role with respect to facts about spin and angular momentum: they can be used to describe what a particular particle's spin state is, how that particle's spin state contributes to that particle's total angular momentum, and so on. In this respect, the roles played by U, D, and the S_r in quantum mechanics are analogous to the roles played by momentum, or distance, or even mass in classical mechanics. Momentum properties, distance properties, and mass properties play a central and fundamental classificatory role in classical mechanics, because they are used to describe the range of possible states which classical particles can exemplify. U, D, and the S_r do likewise for quantum particles.

Second, Lewis claims that to be extremely natural, a property need only feature among the fundamental physical properties of some possible world or other (1986a, p. 60). In the actual world, he claims, physics has its short inventory of extremely natural properties, and that inventory includes spin. So spin properties are extremely natural if they feature,

of the matter as to whether or not both (1) and (2) hold. So there is no fact of the matter as to whether or not U is independent of accompaniment.

[13]There is a prominent misconception that in Bohmian mechanics, lonely particles cannot have spin because spin is only had relative to measuring devices. Just like in all other interpretations of quantum mechanics, however, the trajectories of lonely particles in Bohmian mechanics are characterized by pure quantum states (Norsen, 2014). So lonely particles always exemplify pure states such as U, D, and the S_r.

centrally, in our best current theory of fundamental physics; and Lewis thinks that they do. Of course, he might be wrong about that. Our best current theory of fundamental physics might turn out to be false, or our best current theory might turn out to be non-fundamental. But it is still metaphysically possible that spin features in the best fundamental physical theory of the world. So at some possible world, spin properties are among that world's fundamental physical properties. And so by Lewis's account, spin properties are extremely natural.

Third, it is reasonable to suppose that U, D, and the S_r are neither disjunctive properties nor negated disjunctive properties, because there are no good candidates to serve as the more natural disjuncts. There are no other properties in quantum mechanics like them: that is why they are fundamental to the theory. In addition, spin has no cousin in classical mechanics; it is a uniquely quantum property. And it is quite different from any property in the macro-sized world of tables and chairs. So it is implausible to suppose that the disjuncts could be found among the other properties of microphysics, or among the properties of classical physics, or among properties in the macro world.

Fourth, other accounts of naturalness also imply that U, D, and the S_r are extremely natural. Consider the resemblance conception, according to which the natural properties are those whose "sharing makes for resemblance" (Lewis, 1983b, p. 347) among the objects that exemplify them. U, D, and the S_r do a better job of capturing resemblances in angular momentum—specifically, a part of angular momentum that is independent of orbital momentum—than any other known property. That is why they are used in quantum theory. If there were a better way to capture similarities in momentum, physicists would probably use those in place of spin.

So U, D, and the S_r are independent of accompaniment, and they are neither disjunctive properties nor the negations of disjunctive properties. It follows that, according to Langton and Lewis's analysis, U, D, and the S_r are basic intrinsic, and so intrinsic.[14] Note that this

[14] The conclusion that each S_r is intrinsic, given that the characterization of the S_r presented in §3 mentions

classification agrees with the nomenclature used in the physics literature. As a standard textbook puts it, "the electron has 'intrinsic' angular momentum, not associated with its orbital motion. This angular momentum is called spin" (Shankar, 1994, p. 374).

Perhaps this is the intuitively correct classification, or perhaps not. Set those considerations aside, for Langton and Lewis's analysis faces a deeper issue. If we make a reasonable assumption about duplication—an assumption which is extremely hard to deny, without also giving up Langton and Lewis's analysis of intrinsicality—and plug that assumption into Langton and Lewis's analysis directly, then it follows that at least one of U, D, or the S_r are non-intrinsic. In other words, given that assumption, the second half of Langton and Lewis's analysis classifies spin differently from the first half.

To see how, recall the entangled particles e and p from §3. As was discussed, e does not have any of U, D, or the S_r. For e has $SE(U, D)$, and $SE(U, D)$ is incompatible with those other properties.

Now for the reasonable assumption: suppose that there exists an unentangled electron duplicate e' of e. That is, e' is a duplicate of e and e only; e' is not entangled with anything (even though e is). Note that e' is an electron because e has the property *is an electron*, that property is intrinsic,[15] and duplicates share intrinsic properties. And to be an electron,

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measurement devices, might seem odd. Strictly speaking, however, that is not the fully rigorous definition of the S_r; I presented that characterization merely in order to keep things accessible. Strictly speaking, each S_r is defined in terms of quantum states only, not measurements: see footnote **??** for that fully rigorous definition.

[15]Here is an argument for the claim that *is an electron* is intrinsic, according to Langton and Lewis's analysis. That property can be expressed as a conjunction of the property of having spin $\frac{1}{2}$, the property of having a certain mass, the property of having a certain charge, and so on. If each of those properties in the conjunction is intrinsic, then Langton and Lewis's analysis implies that *is an electron* is intrinsic too. And each of those properties in the conjunction is, indeed, intrinsic. To see why, let us focus on the property—call it 'S'—of having spin $\frac{1}{2}$; similar lines of thought show that the other properties are intrinsic too. S can be expressed as a disjunction of U, D, the S_r, and all properties expressed by predicates of the form 'stands in a spin $\frac{1}{2}$ entanglement relation with something'. Then S is independent of accompaniment: a

the spin of e' must be either U, D, or some S_r,[16] since those are the possible spins that unentangled electrons can have.[17] But as was just pointed out, e does not exemplify any of those properties. So whichever spin property is exemplified by e' is not exemplified by e.

It follows that either U, D, or some S_r is non-intrinsic. For according to Langton and Lewis, a property is intrinsic if and only if it is always shared among duplicates. Since e and e' are duplicates, it follows that there is a non-intrinsic spin property: whichever of U, D, or the S_r is exemplified by e'.

So here is the puzzle. U, D, and the S_r are intrinsic according to that part of Langton and Lewis's analysis that uses naturalness and disjunctive properties. But given the reasonable assumption, at least one of U, D, or the S_r are non-intrinsic, according to that part of Langton and Lewis's analysis that uses duplication.

The puzzle is quite robust. As mentioned in §1, the puzzle is independent of the metaphysics of spin at the actual world. So long as the U, D, and S_r properties are possible, Langton and Lewis's analysis faces this puzzle.

An obvious response is available to proponents of Langton and Lewis's analysis: reject the reasonable assumption. Claim that despite appearances, entangled electrons do not have unentangled duplicates. This response might itself seem reasonable, especially because part

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lonely object can have it (by having, say, U), a lonely object can lack it (by having spin 0), an accompanied object can have it (by having U), and an accompanied object can lack it (by having spin 0). And S is not a disjunctive property. For in order to be a disjunctive property, S must be less natural than *each* of its disjuncts. But for two reasons, that is not so: first, S seems more natural than the properties expressed by predicates of the form 'stands in a spin $\frac{1}{2}$ entanglement relation with something', since those properties are more complicated (it takes more logical vocabulary to express them, for instance); second, S seems about as natural as unentangled spin properties like U or D. For similar reasons, S is not the negation of a disjunctive property. So by Langton and Lewis's analysis, S is a basic intrinsic property, and so S is intrinsic.

[16]For brevity, I ignore superposition spin states of $|U\rangle$ and $|D\rangle$ with complex-valued coefficients. The exact same point applies to spin states like those, however.

[17]This follows from several accounts of what it is to be an electron. For instance, it follows from the account of the property *is an electron* mentioned in footnote 15.

of Langton and Lewis's theory suggests it. After all, as was shown earlier, U, D, and the S_r are basic intrinsic. So according to Langton and Lewis's analysis of duplication, any two duplicates either both have, or both lack, each of those spin properties. Since e' has one of them and e does not, Langton and Lewis's analysis implies that e' is not a duplicate of e. Of course, this response comes with a rather substantive cost: pre-theoretically, any two electrons seem like duplicates of each other, and this response denies that. But perhaps that cost is worth paying.

The cost is far greater than that, however. For this response generates a bigger issue: what does Langton and Lewis's analysis say about the duplicates of e? Langton and Lewis's analysis of duplication must imply *something* about whether e has unentangled duplicates. What does it imply? Does e have any duplicates apart from itself? Does it have any unentangled duplicates? Does it have any entangled duplicates?

These questions are surprisingly hard to address. Consider the following answer: every duplicate of e is entangled with something. More precisely, and more generally, consider the following view: duplicates of proper parts of entangled systems only exist in duplicates of the system as a whole. So on this view, every duplicate of e is a proper part of a duplicate of the entire e-and-p system.

This view faces a puzzle like the one discussed above. On its own, Langton and Lewis's analysis classifies the property $SE(U, D)$ as non-intrinsic. But in conjunction with the proposed view, Langton and Lewis's analysis implies that $SE(U, D)$ is intrinsic. To see that $SE(U, D)$ is non-intrinsic on Langton and Lewis's analysis, just note that it fails to be independent of accompaniment: a lonely object cannot instantiate it.[18] To see that $SE(U, D)$ is intrinsic, however, given the conjunction of Langton and Lewis's analysis and the proposed view, note the following: $SE(U, D)$ is intrinsic if and only if whenever x and x' are duplicates,

[18] Langton and Lewis assume that every accompanied thing has a lonely duplicate, and that every lonely thing has an accompanied duplicate (1998, p. 334). From this assumption, it follows that (contingent) intrinsic properties are independent of accompaniment.

x has $SE(U, D)$ just in case x' has $SE(U, D)$. So let x be e and let x' be a duplicate of e; call it $e^\star$. According to the proposed view, the only duplicates of e are parts of duplicates of the entire e-and-p system. So $e^\star$ is entangled with some positron $p^\star$ in exactly the same way that e is entangled with p. It follows that $e^\star$ has $SE(U, D)$. Since this holds for any duplicate of e, Langton and Lewis's analysis—in conjunction with the proposed view—implies that $SE(U, D)$ is intrinsic. So plausible as the proposed view might be, it cannot rescue Langton and Lewis's analysis from the puzzle. When combined with Langton and Lewis's analysis, the proposed view generates the same sort of puzzle as before.

Other accounts of the duplicates of e, despite their plausibility, also clash with Langton and Lewis's analysis of intrinsicality. For instance, suppose that e does have an unentangled duplicate e': this duplicate exists, perhaps, at a nomologically impossible world.[19] Then Langton and Lewis's analysis correctly classifies $SE(U, D)$ as non-intrinsic, since duplicates can differ over it. But the original puzzle recurs; for this account of the duplicates of e is basically just the reasonable assumption that led to the puzzle in the first place. In particular, if e' is a duplicate of e, then—as argued earlier—e' is an electron. It follows that since e' is unentangled, it must have U, D, or one of the S_r. Since e does not have any of those properties, it follows that at least one of U, D, or the S_r can differ between duplicates. So at least one of U, D, or the S_r is non-intrinsic. And that contradicts the part of Langton and Lewis's analysis which—using naturalness and disjunctive properties—classified each of U, D, and the S_r as intrinsic. The puzzle has returned.

Alternatively, suppose electrons e and e' are duplicates just in case the probabilities for the outcomes of spin measurements on e alone are equal to the probabilities for the outcomes of corresponding spin measurements on e' alone.[20] Then another problem arises for Langton and Lewis's analysis of intrinsicality. Their analysis implies that a thing has its intrinsic properties independently of its relations to wholly distinct things (Lewis, 1983a,

[19]Thanks to an anonymous reviewer for suggesting this.

[20]More precisely: e and e' are duplicates just in case e and e' have the same density operator.

p. 197; 2001, p. 382). But the probabilities for the outcomes of spin measurements on an entangled electron e are not independent in that way. For e has those properties in virtue of the entanglement relation between e and p.[21] So this account of the duplicates of e—though independently plausible—is incompatible with Langton and Lewis's analysis.

Finally, suppose that e has no duplicates apart from itself. This view is highly problematic too: it cannot be used to rescue Langton and Lewis's analysis from the puzzle, because it cannot be consistently combined with their analysis of duplication. Like any other object, e exemplifies some basic intrinsic properties. If there is a possible object x distinct from e with exactly the basic intrinsic properties that e has, then according to Langton and Lewis's analysis of duplication, e and x are duplicates. So if such an x exists, then Langton and Lewis's analysis is inconsistent with this account of the duplicates of e. And there does seem to be such an x.[22] To see why, recall the entangled system consisting of electron $e^\star$ and positron $p^\star$, where both $e^\star$ and $p^\star$ exemplify $SE(U, D)$. Electrons e and $e^\star$ seem like they have exactly the same basic intrinsic properties. If so, however, then by Langton and Lewis's analysis, e and $e^\star$ are non-identical duplicates. Again, we have a contradiction.

So here is the state of play. To get out of the puzzle, proponents of Langton and Lewis's analysis might reject the reasonable assumption that entangled electrons can have unentangled duplicates. But if they do so, then they need to supply an alternative account of the duplicates of entangled electrons like e. And those alternative accounts face problems: they lead to puzzles like the original one, or they contradict some other aspect of Langton and Lewis's approach to intrinsicality and duplication. Therefore, the reasonable assumption is indeed very reasonable. Better to reject Langton and Lewis's analysis than to reject the reasonable assumption.

[21] In terms of density operators: e has its particular density operator in virtue of being entangled with p.

[22] Moreover, Langton and Lewis commit to such an x. As mentioned in footnote 18, Langton and Lewis assume that every accompanied thing has a lonely duplicate. So there is a possible, non-actual x such that x is a duplicate of e.

One might object that Langton and Lewis's analysis was not intended to cover properties like U, D, and the S_r. Spin properties, one might claim, are not in the purview of their analysis. But that is not so: Langton and Lewis's analysis was never intended to be so restricted. It was intended to provide a complete classification of all qualitative properties whatsoever (Langton & Lewis, 1998, p. 334). U, D, and the S_r are qualitative, and so Langton and Lewis's analysis was meant to cover them.

Alternatively, one might respond to the puzzle by restricting Langton and Lewis's analysis to non-quantum properties.[23] Regardless of Langton and Lewis's original intentions, the puzzle shows that their analysis cannot handle properties that are susceptible to entanglement. Nevertheless, one might claim, it does not follow that Langton and Lewis's analysis is completely wrong. Perhaps Langton and Lewis's analysis is applicable in certain circumscribed domains. In particular, perhaps Langton and Lewis's analysis applies to properties that lie outside the quantum realm.[24]

This response seems reasonable to me; I will not explore it here, but only for lack of space. It is worth noting, however, that this response faces the following question: does the notion of intrinsicality apply to the quantum realm? If so, then Langton and Lewis's analysis is incomplete: it does not cover all intrinsic and non-intrinsic properties whatsoever. And a host of new questions will arise, when trying to analyze intrinsicality at the quantum level.[25] But if not, then many philosophical views will need to be revised or abandoned. For many philosophical views assume that the notion of intrinsicality applies at the level

[23]Thanks to an anonymous reviewer for this suggestion.

[24]The view discussed in footnote 12 motivates this response. For according to that view, there is no fact of the matter as to whether a property like U is independent of accompaniment. So plausibly, Langton and Lewis's analysis of intrinsicality simply does not apply to properties like U. For another analysis which allows properties to be neither intrinsic nor non-intrinsic, see (Figdor, 2008).

[25]For instance, how should that kind of intrinsicality be analyzed? And how does that analysis – and the attendant notion of intrinsicality – relate to Langton and Lewis's analysis – and that notion of intrinsicality? Are they related in name only? Or does something more substantial unite them?

of the fundamental. Lewis's thesis of Humean supervenience, for instance, assumes that fundamental physical properties—instantiated by particles, spacetime points, and so on—are intrinsic. So if properties like U and D are neither intrinsic nor non-intrinsic—in the sense that analyses of intrinsicality do not apply to them—then Lewis's formulation of Humean supervenience is based on a false assumption. So the thesis of Humean supervenience must be either reformulated, or just given up.

5 The wavefunction

In the puzzle of §4, I assumed that spin is a property of particles. Since my aim was to explicate a puzzle for Langton and Lewis's analysis by using some standard views of quantum properties, this was a reasonable assumption to make. But there is another kind of thing that could exemplify spin properties: quantum mechanical wavefunctions. So it is worth exploring how Langton and Lewis's analysis fares when spin is assumed to be a property of wavefunctions instead.

In this section, I explore Langton and Lewis's analysis in light of an interpretation of quantum mechanics—a version of the Everett interpretation—which makes that assumption.[26] As shall become clear, my discussion is pretty preliminary, and not completely conclusive: a thorough discussion of the issues that arise, when attempting to combine Langton and Lewis's analysis with this version of the Everett interpretation, is beyond the scope of this paper. But the discussion here points to some interesting problems that face any such attempts. The problems stem from the fact that according to this version of the Everett interpretation, spin properties are exemplified by parts of the wavefunction. And it is not

[26]For lack of space, I will not discuss other interpretations here. Suffice to say that other interpretations generate the same sorts of problems for Langton and Lewis's analysis that this version of the Everett interpretation generates. For instance, the same sorts of problems arise on standard versions of the Bohmian interpretation of quantum mechanics, such as the version discussed in (Albert, 1996).

clear how the notion of loneliness applies to wavefunction parts. So Langton and Lewis's analysis, because it is based on those notions, seems to have some problematic implications.

According to this version of the Everett interpretation, the wavefunction is a physical field; like the electromagnetic field of classical electrodynamics. So the wavefunction is in the world's ontology. Unlike the electromagnetic field, however, the wavefunction is a field on a massively high-dimensional space called 'configuration space'. This space—and not the manifest, three-dimensional space we see around us—is the fundamental physical space of the world. The objects of ordinary experience still exist, of course. But they are emergent, non-fundamental patterns in the wavefunction. Tigers, for instance, are wavefunction patterns that exhibit tiger-like behavior (Wallace, 2003, p. 93). Electrons are emergent patterns in the underlying quantum field (Wallace, 2003, p. 95).

It is unclear whether, on this interpretation, Langton and Lewis's analysis faces any puzzles analogous to the one in §4. That depends on whether their analysis can overcome the following, more basic issues. Patterns, presumably, are proper subsets of the wavefunction.[27] Are those the sorts of things that can be lonely? Many proper subsets are only partial fields, since they do not take values on all of configuration space. And many are not normalized: that is, many do not have modulus squared integral equal to one. So is it possible for objects like that to exist on their own? Arguably, no.[28] Arguably, proper subsets of wavefunctions only exist at worlds where the rest of the wavefunction—or at least, where the rest of some wavefunction or other—exists. But this has bizarre implications. For instance, given that particles are proper subsets of wavefunctions, it follows that the property of being a particle is not independent of accompaniment: lonely objects cannot instantiate that property. So the property of being a particle is not intrinsic. Similarly for all other properties that particles exemplify. In fact, similarly for most all other properties which are exemplified by patterns

[27]More precisely: a pattern is, presumably, a proper subfield of the wavefunction's assignment of complex values to configuration space points.

[28]Thanks to an anonymous reviewer for this suggestion.

in the wavefunction: the property of being a tiger, the property of being 100 grams in mass, the property of being cubical, the property of being red, and so on. And since most all physical objects—you, me, this coffee mug, that table, and so on—are patterns in the wavefunction, it follows that most all physical objects do not exemplify intrinsic properties. For according to Langton and Lewis's analysis, none of the properties of those physical objects are independent of accompaniment. So none of those properties are intrinsic. And that result seems problematic.[29]

Langton and Lewis based their analysis of intrinsicality on notions that, when combined with this version of the Everett interpretation, lead to significant problems. Of course, my discussion here has been brief: perhaps these problems can be overcome. Maybe it is possible for proper subsets of wavefunctions to exist on their own, for instance.[30] But regardless,

[29]In response to this problematic result, I suggest abandoning Langton and Lewis's analysis. But another response is available: one might argue that this result, though unintuitive, is not *wrong*. Perhaps the world really is that strange. Quantum mechanics is pretty strange, after all: so perhaps we should not be too bothered by the conclusion that most all properties, of most all physical objects, are non-intrinsic (thanks to an anonymous editor for suggesting this). Of course, if this is correct, then lots of views which rely on the intrinsic/non-intrinsic distinction—the views listed in §1, for instance—will be affected: characterizations of the difference between real and 'mere Cambridge' change, views about the supervenience of the psychological on the physical, Lewis's views about perdurantism and Humean supervenience, and so on. In other words, if most all properties of most all physical objects are non-intrinsic, then lots of views will either (i) be wrong, or (ii) have strange and unintuitive consequences of their own. But fans of Langton and Lewis's analysis may be willing to accept those implications, especially given that when it comes to quantum mechanics, a certain amount of strangeness and unintuitiveness is already inevitable.

[30]Even if this is so, however, I still do not see how those lonely proper subsets could exemplify intuitively intrinsic properties like *is a particle* or *has mass*. Subtract the rest of the wavefunction, and the resulting proper subset seems incapable of exemplifying properties like *is a particle*: without the rest of the wavefunction around, that proper subset does not seem like a pattern *in* anything. So I worry that even granting the possibility of lonely proper subsets of wavefunctions, Langton and Lewis's analysis will still imply that many intuitively intrinsic properties—many properties which physicists and philosophers say are intrinsic—are non-intrinsic.

proponents of Langton and Lewis's analysis have their work cut out for them. There appears to be significant tension between (i) some standard interpretations of quantum mechanics, and (ii) Langton and Lewis's analysis of intrinsicality. Proponents of Langton and Lewis's analysis owe us a way of resolving that tension.

6 Conclusion

Lewis's metaphysics is in trouble. His preferred analysis of intrinsicality faces a puzzle which seems hard to avoid. And again, the puzzle generalizes: it arises from any possible properties which are similar, in certain fairly minimal respects, to U, D, and the S_r.

Of course, to avoid the puzzle, fans of Lewis's metaphysics might adopt a different analysis of intrinsicality. I think that is the right response. Fans of Lewis's metaphysics—and detractors too—would be well served by a different analysis. For as the quantum realm shows, there are possible properties which do not cohere well with the analysis provided by Langton and Lewis.[31]

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