

Are There Fundamental Intrinsic Properties?¹

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1. Introduction

David Armstrong once said:

There is a certain picture of the physical world that we all cherish in our hearts, although in our philosophical thinking we may consider ourselves forced to abandon it in a greater or lesser degree. According to this picture, the physical world, including our bodies, consists of a single realm of material objects, and perhaps other objects, related in space and enduring and changing in time. Material objects have shape and size, they move or are at rest, they are hot or cold, hard or soft, rough or smooth, heavy or light, they are coloured, they may have a taste, and they may emit sounds or smells. These properties of objects are, on occasion, perceived; but objects continue to have these properties in a perfectly straightforward way when, as is usually the case, the objects, or particular properties of the objects, are not perceived. This is the picture of the physical world to which we are all instinctively drawn (even Berkeley was). We may think that relatively abstruse evidence garnered from scientific investigations forces us to modify this picture. But it is the picture we have gained through perception, and when we are not considering perception as philosophers, we do not think that the evidence of ordinary perception tends to overthrow it in any way. (1968, pp. 239-40)

This intuitive picture of the physical world tells us that there are material objects located in space and time and possessing properties like shape, size, motion or rest (what Locke called the ‘primary qualities’ and contemporary philosophers call ‘intrinsic properties’) as well as properties like heat, colour, or smell (what both Locke and many contemporary philosophers call ‘secondary qualities’). David Lewis offers a similar picture that adds a tentative commitment to spacetime itself:

We have geometry: a system of external relations of spatiotemporal distance between points. Maybe points of spacetime itself, maybe point-sized bits of matter or aether or fields, maybe both. And at those points we have local

¹ Thanks to David Albert, Allan Hazlett, Barry Loewer, and Ted Sider for enormously helpful discussion and comments on earlier drafts.

qualities: perfectly natural intrinsic properties which need nothing bigger than a point at which to be instantiated. (1986a, pp. ix-x)

These pictures constitute our way of understanding the physical world, in particular the physical world as it is fundamentally. As Armstrong puts it, these material bodies bearing intrinsic properties and spatial and temporal relations to each other are of what the physical world, including our bodies *consists*.

This is no doubt an intuitive picture of the physical world at its most fundamental, a picture we can make sense of, to a large extent can visualize, and one which many of us as metaphysicians indeed do cherish due to our ability to understand it. But is it accurate? Do our best fundamental physical theories confirm this picture? In particular, do our best, fundamental physical theories reveal a physical world consisting of material bodies with intrinsic properties?

Several philosophers have suggested that the answer to these questions is ‘no’. When we consider the picture of fundamental reality given to us by physics, we find only extrinsic properties, relations. We do not find fundamental intrinsic properties. Here is Armstrong again:

[I]f we look at the properties of physical objects that physicists are prepared to allow them, such as mass, electric charge, or momentum, these show a distressing tendency to dissolve into relations that one object has to another. What, then, are the things that have these relations to each other? Must they not have a non-relational nature if they are to sustain relations? But what is this nature? Physics does not tell us. (1968, p. 282)

In a more recent book, James Ladyman and Don Ross argue for a similar conclusion:

Both [quantum mechanics] and relativity theory teach us that the nature of space, time, and matter raises profound challenges for a metaphysics that describes the world as composed of self-subsistent individuals. In so far as quantum particles and spacetime points are individuals, facts about their identity and diversity are not intrinsic to them but rather are determined by the relational structures into

which they enter.... [A]ll the properties of fundamental physics seem to be extrinsic to individual objects. (2007, p. 151)²

Such claims then often lead to worries about whether or not a picture of a world fundamentally consisting of relations, with no fundamental intrinsic properties can even be made coherent. Although some philosophers are willing to accept such a conclusion and happily endorse such a metaphysical structuralism (Ladyman and Ross are a clear example; John Hawthorne (2001) also takes the idea seriously), many cling to the intuitive picture. These philosophers reluctantly end up endorsing a kind of Kantian position: material bodies have fundamental intrinsic properties, but since fundamental physical science only reveals the relations these bodies bear to each other, we can never know how things fundamentally are in themselves, what their fundamental intrinsic properties are.³

Our task here will be to evaluate the truth of this claim: that all of the properties of fundamental physics are extrinsic properties. As I will argue, although certainly a lot of what we might have previously thought were cases of intrinsic properties are revealed by physics to be extrinsic, this does not entail that no properties of fundamental physics are intrinsic. Mass, charge, momentum: these may all be extrinsic properties. However, this does not entail the nonexistence of fundamental physical properties that are intrinsic. Indeed current, fundamental physical theories do posit intrinsic properties, and in doing so are able to support another picture of fundamental reality that we may cherish.

² Similarly negative verdicts regarding the status of intrinsic properties in fundamental physics are discussed by Blackburn (1990), Jackson (1998), Langton (1998), Stoljar (2001), and Lewis (2009).

³ Discussion of such skeptical arguments can be found in my (2007).

We will begin by making more precise the distinction between intrinsic and extrinsic properties that this debate presupposes. The next sections will investigate the status of fundamental intrinsic properties in quantum mechanics. To make the discussion somewhat manageable and compact, I have put off the question of intrinsic properties in relativity theory and our theories of fundamental interactions to another day, though certainly there are more places to look if one wants to know if there exist fundamental intrinsic properties.⁴

2. Intrinsic/Extrinsic

No better synopsis of the intrinsic/extrinsic distinction could be provided than this one from David Lewis:

We distinguish *intrinsic* properties, which things have in virtue of the way they themselves are, from *extrinsic* properties, which they have in virtue of their relations or lack of relations to other things. (1986b, p. 61)

This, I take it, is the basic sense of intrinsic property with which most philosophers work. It is the historical descendent of Locke's notion of a primary quality (1690, II.viii.9-24) and the central notion of intrinsicness with which this paper is concerned. Intrinsic properties are ways things are in themselves, not ways they are with respect to other things. As Lloyd Humberstone puts it, "an intrinsic property is one whose possession just depends on the possessor itself" (1993, p. 239).

When a property is intrinsic, this is a feature of the property itself; it is not a feature of the way we think about the property. Sometimes it is argued that all of the

⁴ My own view is that the metrical and topological properties attributed to spacetime by relativity theory are exemplary cases of fundamental intrinsic properties. Our theories of the fundamental interactions, the gauge theories of e.g. electromagnetism and quantum chromodynamics, also posit intrinsic properties.

properties of science fail to be intrinsic because we only come to know or think about them by way of their structural or causal profiles. In particular, in science we learn about properties by learning about the patterns in which they are instantiated, and how these instantiations affect our senses and the instantiations of other properties. So, it is argued, the properties of science are relational.⁵

It is worth emphasizing that there is another distinction lurking in this argument, however it is not the distinction between intrinsic and extrinsic properties with which we are concerned. And so, such general arguments about “science” cannot give us good reason to think that no fundamental physical property is intrinsic. What arguments like this one rely on is a distinction not between two kinds of properties (intrinsic and extrinsic), but rather a distinction between two ways of thinking about properties (relationally and nonrelationally). In particular, the argument’s suggestion is that in science, all properties are thought of under relational descriptions. Note though that this does not entail that the properties of science are not intrinsic. Frank Jackson makes the point well:

When physicists tell us about the properties they take to be fundamental, they tell us about what these properties *do*. This is no accident. We know about what things are like essentially through the way they impinge on us and on our measuring instruments. It does not follow from this that the fundamental properties of current physics ... are causal cum relational ones. It may be that our terms for the fundamental properties pick out the properties they do via the causal relations the properties enter into, but that at least some of the properties so picked out are intrinsic. (1997, p. 23)

Jackson moves from here to worry that still we might not know these intrinsic properties’ “intrinsic nature” (p. 24). The worry it seems is that we can only come to know these properties under relational descriptions and never under a nonrelational description. The

⁵ This is partly how David Lewis reasons in his (2009).

discussion below will likely give us reason to doubt this claim. However, even if this is right, the point remains that the properties of science are not thereby extrinsic. To see this, suppose for a moment that shapes are intrinsic. The planet Mercury has a particular shape. This is an intrinsic property of Mercury. However, we may think about this property in a relational way. We may think about it relationally under the description ‘the shape of the first planet from the Sun’. Even if we only thought of the shape of Mercury under this relational description, this would not entail that the shape was extrinsic, that it was a property that Mercury had in virtue of its relations to other things. The shape’s intrinsicness or extrinsicness is a fact independent of how we think about it.

To reiterate, just because we may think about a property in terms of its relations to other things (us, the Sun, etc.), this does not entail that the property itself is extrinsic. So an argument that all of the properties of fundamental physics are extrinsic starting from a premise about how we learn about those properties will be a *non sequitur*. The fact that we often come to learn about these properties by virtue of their relations to us or patterns of instantiation is not enough to establish the extrinsicness of these properties. To see whether the properties of fundamental physics are all extrinsic properties, one must instead consider whether these properties tell us how those objects are in themselves, or just merely how they are with respect to other things.

3. Intrinsic Properties in Quantum Mechanics

There are several interesting aspects of quantum mechanics that have been thought to pose a threat to the existence of fundamental intrinsic properties. In this section, we will examine just one kind of argument philosophers seem to have in mind when it is

suggested that quantum mechanics commits us to the denial of fundamental intrinsic properties.⁶ To my knowledge, such an argument has never been carefully formulated, so the first task will be to spell out an argument that appears to have some plausible validity starting from premises about important consequences of quantum mechanics. The argument we will consider is motivated by the fact that quantum mechanics permits systems to evolve into what, following Schrödinger (1935), are known as *entangled states*. Let's begin by getting clear on this central notion of entanglement.

3.1 Entanglement

The quantum state of a system is the system's wavefunction (Ψ). Here, we will use standard bracket (or Dirac) notation to express quantum states. For example, the quantum state of a system of just one particle that is at location (4, 0, 0) will be represented by:

$$\Psi_1 = |(4, 0, 0)\rangle$$

And the quantum state of a system of just one particle that has spin up in the x direction will be represented by:

$$\Psi_2 = |x\text{-spin up}\rangle$$

We can also use the Dirac notation to represent states of multi-particle systems.

Subscripts will then be used to indicate which part represents the state of which particle.

⁶ There is at least one other kind of argument challenging the existence of intrinsic properties in quantum mechanics that I will not discuss. Arguments of this kind appeal to the alleged existence in quantum mechanics of "identical particles", and attempt to deny the existence of particles' intrinsic natures. French and Krause (2007) is a recent book discussing such arguments.

For example, if we want to represent the state of a two particle system in which particle 1 is at location (4, 0, 0) and particle 2 is at location (7, 0, 0), we will write:

$$\Psi_3 = |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2$$

And the state of a two particle system in which particle 1 has x-spin in the up direction and particle 2 has x-spin in the down direction will be represented by:

$$\Psi_4 = |x\text{-spin up}\rangle_1 |x\text{-spin down}\rangle_2$$

Using this notation, we can represent the states of systems of any number of particles.

However, let us briefly return to discuss single particle states. The most interesting thing about quantum mechanics is that it allows for systems to evolve into states that are superpositions; for example, the state in which there is a single particle in a superposition of being at location (4, 0, 0) and being at location (7, 0, 0). This state will be represented in the following way:

$$\Psi_5 = \frac{1}{\sqrt{2}} |(4, 0, 0)\rangle + \frac{1}{\sqrt{2}} |(7, 0, 0)\rangle$$

It is also possible for a system to be in a superposition of spin states. For example, an electron coming out of a z-spin detector will often be said to be in a superposition of having x-spin up and x-spin down:

$$\Psi_6 = \frac{1}{\sqrt{2}} |x\text{-spin up}\rangle + \frac{1}{\sqrt{2}} |x\text{-spin down}\rangle$$

How to understand superpositions like these is one of the central controversies in the philosophy of quantum mechanics. However, there are several things one can say about states like these that are almost entirely uncontroversial.

Let us focus on this last case. To say that a system is in this quantum state is not to say that the particle has x-spin up, nor is it to say that it has x-spin down. It is also not to say that particle has both x-spin up and x-spin down; nor, is it to say that the particle

has neither x-spin up nor x-spin down. One thing that is true of a particle that is in this quantum state is that if the particle's x-spin is measured, then there is a 0.5 chance that it will be found to have x-spin up. And if the particle's x-spin is measured, there is a 0.5 chance that it will be found to have x-spin down. The probability is 0 that the particle will be found to have any other x-spin. These probabilities are given by the square of the coefficients in the representation of the quantum state. When a system is not in a superposition of x-spin, but rather the system's quantum state does entail that it has one or the other of x-spin up or x-spin down, then one says that it is in an *eigenstate* of x-spin, and similarly for other properties of quantum systems. Ψ_2 is an eigenstate of x-spin. Ψ_1 is an eigenstate of position.

So, for the general case, if a system of one particle is in a superposition of being in state A and state B such that its quantum state may be represented in the following way:

$$\Psi = a|A\rangle + b|B\rangle,$$

Then although it is false that this quantum state represents the particle as being in state A, and false that it represents the particle as being in state B, or both state A and state B, or neither state A nor state B, this quantum state does represent the following fact. If one measures the system to determine whether it is in state A or state B, there is a chance of a^2 that the particle will be found in state A, and there is a chance of b^2 that the particle will be found in state B.

All of this so far has been uncontentious. There is one last thing however that must be mentioned that is a matter of controversy. A nearly universal view is that a system's wavefunction encodes complete information about it with respect to the

property in question. For example, if a system is correctly described as being in Ψ_5 , there is nothing more that can truly be said about its position. The particle has a 0.5 chance that it will be found at (4, 0, 0) and a 0.5 chance that it will be found at (7, 0, 0), and that is all. And if a system is correctly described as being in Ψ_6 , there is nothing more that can be said about its x-spin. Perhaps systems may evolve out of superpositions, into states that are eigenstates of position or x-spin, but when they are in these superpositions, their positions or x-spin as the case may be, are not determinately here or there, up or down. To adopt the terminology of Tim Maudlin (2007), this is to say that the quantum state is *ontologically complete*. This is the case according to most contemporary, realist⁷ approaches to quantum mechanics, but not all. In particular, we will talk a bit about the Bohmian approach to quantum mechanics below. Bohmians say that in the case of position, the quantum state is not a complete representation of the state of the particles. According to this view, particles always have determinate positions, even if the system's quantum state is a superposition of position.⁸ Set this aside for now. For most approaches to quantum mechanics, the quantum state is a complete characterization of the system at a time. It is an ontologically complete characterization of the particles' position, x-spin, or what have you.

⁷ By a realist approach, I mean one that takes the theory (in this case, quantum mechanics) to be providing a true description of the world independent of us as observers. There are other approaches to quantum mechanics that would plausibly be considered mainstream (in that they are endorsed by many physicists) that aren't realist. For example, many physicists prefer an information-theoretic understanding of quantum mechanics according to which the theory doesn't describe the world independent of us as observers, but rather the evolution of our states of knowledge as we perform experiments. As this is a paper about the ontology of our fundamental physical theories, I will ignore these sorts of approaches.

⁸ To foreshadow the conclusion that will be reached below, this is because the quantum state Ψ on the Bohmian approach does not describe the state of the particle(s) at all, but the state of something else.

Entangled states are superpositions involving multiparticle systems. For example, we might consider a system of two particles that are entangled with respect to their position:

$$\Psi_7 = \sqrt{1/2} |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2 + \sqrt{1/2} |(7, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2$$

What is true of particles in such a state? On the assumption that the quantum state is ontologically complete, it is not true that either particle has a determinate location, either of being at (4, 0, 0) or of being at (7, 0, 0). However, it is true that if one were to successfully measure the positions of the particles, they would be found in one of the following two states. There is a 0.5 chance that particle 1 would be found at (4, 0, 0) and particle 2 would be found at (7, 0, 0). And there is a 0.5 chance that particle 1 would be found at (7, 0, 0) and particle 2 would be found at (4, 0, 0). And these are the only possibilities. It is natural to conclude from this fact that although neither particle in Ψ_7 has a determinate position, the relation between the positions of the two particles is determinate. For, there is a probability 1 that the particles will be found at a distance of 3 from each other.

Particles can be in entangled states of position, momentum, spin, and so on. Many philosophers have tried to parlay these facts about entangled systems into a case against the existence of fundamental intrinsic properties. To see how this goes, we will use the example of the singlet state, to be explained momentarily. The reason we will use this state for the discussion is the following. As I've said, there exist entangled states of particle positions. However, most philosophers do not think of positions as intrinsic properties. If anything, they are relations objects bear to spacetime, or if one is a relationalist about spacetime, then relations objects bear to other objects. So, considering

entanglements of position will not show us that objects fail to have intrinsic properties of the kind we thought they had. The singlet state on the other hand involves the spin properties of particles. These are the kind of properties that philosophers often take to be intrinsic. So, if we can show that quantum mechanics reveals that all of the spin properties of objects are extrinsic, this will be useful for formulating an argument against the existence of intrinsic properties in quantum mechanics.

The singlet state can be represented in the following way:

$$\Psi_{\text{singlet}} = \frac{1}{\sqrt{2}} |x\text{-spin up}\rangle_1 |x\text{-spin down}\rangle_2 - \frac{1}{\sqrt{2}} |x\text{-spin down}\rangle_1 |x\text{-spin up}\rangle_2$$

When two particles are in the singlet state, neither can individually be said to have a determinate x-spin. So even if spin properties like x-spin up or x-spin down are intrinsic, they are not the sort of properties that particles in states like the singlet state possess. It is rather only the case (given the ontological completeness of the quantum state) for particle 1 that it has the extrinsic property of having the opposite x-spin of particle 2, and for particle 2 that it has the extrinsic property of having the opposite x-spin of particle 1. At best, the spin properties attributed to particles by virtue of their entering into entangled spin states are extrinsic spin properties.⁹

3.2 From Entanglement to the Denial of Intrinsic Properties

The argument from the existence of entangled states to the universal denial of intrinsic properties in quantum mechanics has three parts. First, one establishes that there exist

⁹ Some readers will be aware that particles in superpositions of x-spin are often said to simultaneously be in eigenstates of z-spin. At this point, I am only trying to motivate the claim that entities entangled with respect to one kind of property (here, x-spin) lack intrinsic properties of that kind. In the next section, we will consider reasons to doubt the claim that entities are ever in eigenstates of any properties.

certain entangled states, and that such states characterize systems merely in terms of extrinsic properties. Second, one argues that the initial quantum state of all the particles in the universe is an entangled state. Finally, one argues that systems never evolve out of entangled states – once entangled, always entangled.

We have already seen examples of entangled states. The existence of such states has been confirmed repeatedly by experiment since they were initially predicted to be a consequence of quantum mechanics. On those approaches that take the quantum state of a system to be complete, systems in entanglements of x-spin will only have extrinsic x-spin properties, those in entanglements of momentum will only have extrinsic momenta, and so on. We noted above that most approaches to quantum mechanics do take the quantum state of a system to be complete. So, according to these views, systems that are entangled with respect to all of their quantum mechanical properties will fail to have any such intrinsic properties. An exception to the completeness view we noted above was the Bohmian approach. Here by contrast, the quantum state of a system is not ontologically complete because on this view, particles always have determinate positions, even if the system is entangled with respect to position. Nevertheless, even the Bohmian approach can allow that quantum mechanics only allows entangled particles extrinsic properties since positions are not intrinsic properties.

It is common to argue for the next step, that the initial quantum state of all the particles in the universe is an entangled state, by appealing to the Big Bang as the initial state of the universe.¹⁰ This initial state was one so enormously entangled that it is

¹⁰ A similar premise is used by Jonathan Schaffer (forthcoming) in defense of his view that the universe as a whole, as opposed to its individual particle parts, is what is fundamental. We will discuss a position that is similar in some ways to Schaffer's below.

correctly described as one that is a superposition of particle cardinality. The initial quantum state is one in which particles are entangled with respect to all of their properties, indeed even their properties of identity and diversity.¹¹ Combining the first and second steps, we are led to the conclusion that quantum mechanics does not ascribe intrinsic properties in the initial quantum state of the universe.

The question is then whether systems ever evolve out of entangled states into eigenstates of spin, momentum, or what have you so that they may be accurately described as instantiating fundamental intrinsic properties. If we just consult the Schrödinger equation, the central dynamical law of quantum mechanics, the answer would appear to be ‘no’. There is nothing about the law analytically ruling out the evolution of systems from entangled states into states that are separable with respect to position, x-spin, etc.¹² Nevertheless, given the universe’s initial state, the actual likelihood that a system will ever evolve via the Schrödinger equation into anything like separable state is (on any reasonable probability distribution) zero.¹³ Several approaches to quantum mechanics take the Schrödinger equation to be a dynamical law that is never violated. This is true of both the Everett or many worlds approach to quantum mechanics as well as Bohmian mechanics.

However, there exist other approaches to quantum mechanics according to which the Schrödinger equation is at times violated. And this may allow particles to evolve out

¹¹ Some take this to indicate that this is an initial state in which the number of particles is zero.

¹² David Albert (p.c.) mentions the possibility, consistent with Schrödinger evolution, of the time-reverse of a process in which a system enters an entangled state from an initial state that is unentangled (separable).

¹³ Given the fact that the Schrödinger equation is deterministic, what is being described here is a subjective likelihood.

of entangled states of one or another property, into eigenstates of that property.

According to the traditional (sometimes called the ‘orthodox’) approach to quantum mechanics advocated by von Neumann (1955), systems evolve linearly according to the Schrödinger equation until a measurement on the system takes place at which point systems in a superposition will collapse onto one or another eigenstate. The Schrödinger equation is also at times violated according to the approach to quantum mechanics advocated by Ghirardi, Rimini, and Weber (1986). According to GRW, systems evolve out of superpositions spontaneously with a probability proportional to the complexity of the system. So, it looks like on what are often called ‘collapse approaches’ to quantum mechanics, systems can evolve into eigenstates in which particles are correctly described as individually instantiating intrinsic properties like spin.

Now, it is often pointed out (for example, in Schaffer forthcoming) that even if systems do sometimes evolve out of entanglements of one or another property, quantum mechanics entails that they will very quickly evolve right back into them, and so even if particles do seem to have fundamental intrinsic properties, these instantiations never last for very long. This is true, however, this response does not seem satisfactory if we are interested in giving an argument for the claim that quantum mechanics *never* ascribes intrinsic properties to particles.

What instead needs to be noted is that even on a plausible collapse approach, systems never quite evolve completely out of entanglements.¹⁴ Rather, what happens in collapse is that systems evolve into states which are very nearly eigenstates, but only very nearly. To see why, let’s return back to consider the simple entangled state of position:

¹⁴ This is what leads to what is often called ‘the tails problem’ for collapse theories.

$$\Psi_7 = \sqrt{1/2} |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2 + \sqrt{1/2} |(7, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2$$

Now, if it were the case that such a state could evolve into an eigenstate of position, then this would mean it could collapse into one or the other of Ψ_8 or Ψ_9 :

$$\Psi_8 = |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2$$

$$\Psi_9 = |(7, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2$$

And if this were the case then we could know for sure where the particles were; because they would each have a determinate position. However, this cannot be what happens in a collapse, for if it were then this would entail a very high momentum and hence energy for the particles that would wildly violate conservation principles. Instead, upon collapse, the system evolves into one or the other of Ψ_{10} or Ψ_{11} :

$$\Psi_{10} = \sqrt{p} |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2 + \sqrt{(1-p)} |(7, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2$$

$$\Psi_{11} = \sqrt{(1-p)} |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2 + \sqrt{p} |(7, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2,$$

where p is very close to, but not equal to 1.

Why would the system's collapsing completely onto an eigenstate for position entail an objectionably high energy? Consider Heisenberg's uncertainty principle. This entails that the determinateness of a system's position and energy states are related in such a way that as the indeterminateness of the position gets very small, the indeterminateness of the system's energy gets very large. If the system were in an eigenstate of position (i.e. a state in which the indeterminateness with respect to position of the particles is zero), then the indeterminateness in its energy would be infinite. This then would make it extremely likely that the system's energy is extremely high, as there are far more ways for it to be

very high than low. So, the collapse of systems completely into eigenstates of position would entail enormous violations of energy conservation.¹⁵

What all of this entails is that entangled systems stay entangled. This is true whether we are considering a view according to which quantum states collapse or one according to which they do not. And now we can conclude the argument of this section. Since the universe began in a state in which all particles were entangled, and does not evolve out of entanglement, and since quantum mechanics does not attribute intrinsic properties to systems in entangled states, quantum mechanics does not attribute intrinsic properties to systems in our universe.

3.3 Realism about the Wavefunction

Although this argument appears compelling, I want to show here that its conclusion should not be accepted. Indeed despite the availability of such an argument, all mainstream, realist approaches to quantum mechanics do take it that quantum mechanics attributes intrinsic properties to systems in our universe, and so the argument of the previous section is unsound.

The problem with the argument is not in its claims regarding the pervasiveness of entanglement, but rather with its first step. It is not correct to say that quantum mechanics characterizes systems in entangled states completely in terms of extrinsic properties. We have seen good reason to accept that quantum mechanics will not attribute intrinsic properties to particles in entangled states, but on any mainstream, realist

¹⁵ Analogous considerations lead to the conclusion that particles in superpositions of spin (x-spin or z-spin, etc.) will never completely collapse into their respective eigenstates.

approach, quantum mechanics will attribute intrinsic properties to something else: the wavefunction.

Up to now, I have been speaking as if the wavefunction is some linguistic or mathematical entity used merely to describe the state of a system in quantum mechanics. However, what the phenomenon of entanglement shows us is that we must take the wavefunction to be more than this; indeed, we must accept it as a real element in our ontology. The initial case for wavefunction realism is stated well by Peter Lewis:

The wavefunction figures in quantum mechanics in much the same way that particle configurations figure in classical mechanics; its evolution over time successfully explains our observations. So absent some compelling argument to the contrary, the prima facie conclusion is that the wavefunction should be accorded the same status that we used to accord to particle configurations. (2004, p. 714)

There is also an argument for taking the wavefunction with ontological seriousness that is relatively simple. It can be summarized in the following way:

- (1) There exist entangled states.
- (2) These states cannot be adequately characterized as states of something inhabiting a three dimensional space, but rather must be characterized as spread out in a higher dimensional configuration space.
- (3) So, (from 1 and 2) there is something of the kind that must be characterized as spread out in a higher dimensional configuration space: call this the ‘wavefunction’.
- (4) So, the wavefunction exists.¹⁶

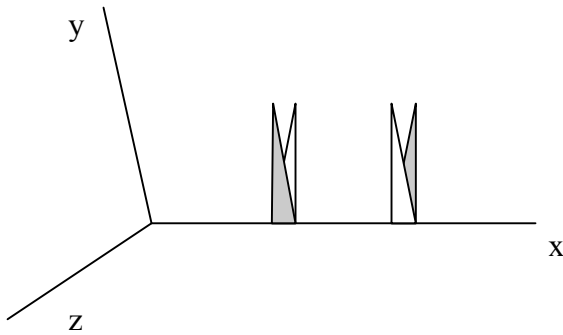
The crucial premise is the second one. To see why, let us return to the example of the entangled state of position:

¹⁶ A similar kind of argument is given by Peter Lewis (2004). David Albert (1996) also endorses the conclusion, following John Bell (1987).

$$\Psi_7 = \sqrt{1/2} |(4, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2 + \sqrt{1/2} |(7, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2$$

Could this be the state of something existing in a three dimensional space? One thing you might think is that this is a state that is had by an object spread out in three dimensional space in virtue of instantiating certain intensities at various locations. Then we can capture what is represented by Ψ_7 by taking there to be two peaks of intensity 0.5 at each of the two locations, (4, 0, 0) and (7, 0, 0), in three dimensional space. On the figure below, this is illustrated using gray peaks for the intensities of particle 1, and white peaks for those of particle 2.

Fig. 1



The trouble with trying to view quantum states in this way, as states of something spread out in three dimensional space, can be seen by considering an empirically distinguishable state that we may call ‘ Ψ_{12} ’:

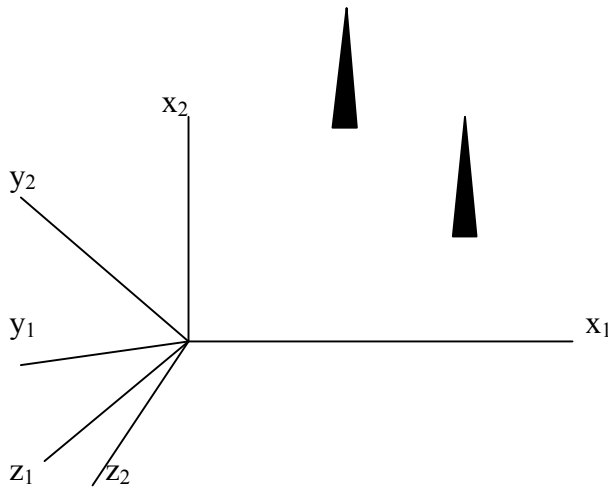
$$\Psi_{12} = \sqrt{1/2} |(4, 0, 0)\rangle_1 |(4, 0, 0)\rangle_2 + \sqrt{1/2} |(7, 0, 0)\rangle_1 |(7, 0, 0)\rangle_2$$

Ψ_{12} is clearly a distinct quantum state from Ψ_7 . Unlike Ψ_7 , if we try to test whether this state obtains, we will find particles not at distinct locations three units apart, but instead two particles at the same location. However, try to understand Ψ_{12} as the state of something spread out in a three dimensional space and we wind up being unable to

distinguish it from Ψ_7 .¹⁷ And this is in general the case. Empirically distinct entangled states cannot be adequately distinguished unless they are understood to be states of something spread out in a higher-dimensional, what is called ‘configuration space’. Once we modify our ontology and consider the quantum state to be the state of something in this configuration space, Ψ_7 and Ψ_{12} can be seen clearly to be distinct.

The configuration space that is used to represent quantum states is standardly introduced as having $3N$ dimensions, where N is the number of particles in the system. The first three coordinates in the configuration space may be taken to correspond to x , y , and z coordinates for particle 1, the second three coordinates in the configuration space correspond to x , y , and z coordinates for particle 2, and so on. Now, Ψ_7 can be taken as describing intensities at locations $(4, 0, 0, 7, 0, 0)$ and $(7, 0, 0, 4, 0, 0)$ in the six dimensional configuration space. The following diagram illustrates this:

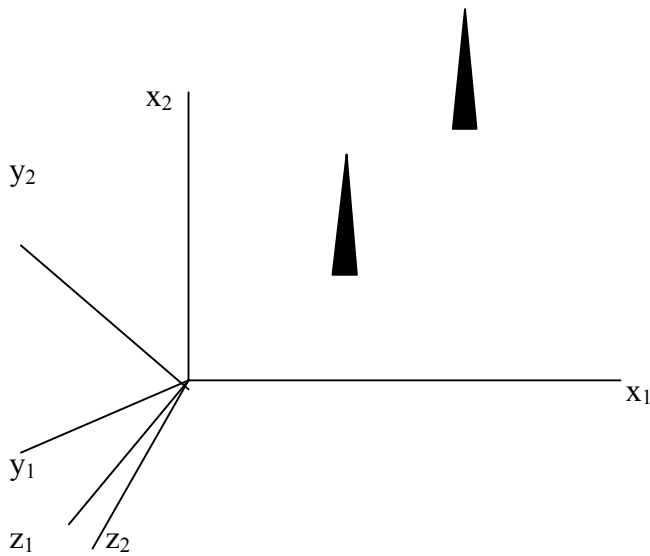
Fig. 2



In configuration space, Ψ_{12} constitutes a completely different state that can be represented this way:

¹⁷ The reader can check this against Fig. 1.

Fig. 3



For a system in Ψ_{12} , non-zero intensities in the configuration space occur only at locations $(4, 0, 0, 4, 0, 0)$ and $(7, 0, 0, 7, 0, 0)$.

So, entangled states can only be distinguished if we assume they are states of something with intensities in a higher-than-three dimensional configuration space. This is the quantum wavefunction.

As David Albert puts it, criticizing the anti-realism and confusion pervasive in early attempts to understand quantum mechanics:

[I]t has consequently been essential to the project of digging one's way *out* of those sorts of confusion, it has been essential (that is) to the project of quantum-mechanical *realism* (in *whatever* particular form it takes – Bohm's theory, or modal theories, or Everettian theories, or theories of spontaneous localization [GRW]), to learn to think of wave functions as physical objects *in and of themselves*. (1996, p. 277)

But what kind of entity is the wavefunction? The wavefunction is understood by most authors (including Albert) as a field. John Bell is extremely clear on this point, saying:

No one can understand this theory until he is willing to think of Ψ [the wavefunction] as a real objective field rather than just a 'probability amplitude'. Even though it propagates not in 3-space but in $3N$ -space. (1987, p. 128)

What it means to characterize the wavefunction as a field is simply to take it to be an entity that pervades all of space and has amplitude and phase at each point in this space (in this case, configuration space). These amplitudes were represented by peaks on the last two diagrams, and they are intrinsic properties of a quantum mechanical entity whose instantiations are located at points.¹⁸

The phenomenon of quantum entanglement shows us that we cannot represent quantum systems as systems of particles instantiating intrinsic properties. But this is only half of the story. For recognition of quantum entanglement shows us that in order to capture the complete facts of entanglement we must accept a wavefunction ontology. Once we do so, we see that quantum systems do instantiate intrinsic properties. However these are not intrinsic properties of the particles, but intrinsic properties of the wavefunction – its phase and amplitude at points. So, it is wrong to think that quantum mechanics shows us that there are no fundamental intrinsic properties.

One might be dissatisfied with this response to the argument of the previous section and think that it misses the point of the argument against fundamental intrinsics. The thought is that even if it is the case that quantum mechanics allows for the instantiation of some intrinsic properties, those instantiated by the wavefunction, still there is an important sense in which we learn from quantum mechanics that the fundamental properties of *our* world, those that are instantiated by those things that most fundamentally constitute us, are all of them extrinsic. For, the wavefunction is something external to us and the physical world we inhabit. Indeed it is something altogether

¹⁸ See also Barry Loewer (1996) for discussion of this point, that these amplitudes are intrinsic properties of the wavefunction.

external to our shared, three dimensional physical world, occupying its own $3N$ dimensional configuration space. Therefore, it is consistent with the above points about wavefunction realism, that the fundamental properties of our world, those that constitute things like people, tables, chairs, and planets, are all extrinsic properties. And so we do indeed have to revise our intuitive picture of the world as one that involves fundamentally the instantiation of intrinsic properties.

This is a tempting way of viewing the lessons of quantum mechanics for fundamental ontology. Indeed this seems to be the most straightforward way to understand the ontology of the Bohmian approach to quantum mechanics. What the theory posits is two distinct kinds of entities inhabiting two separate spaces. There is the wavefunction inhabiting a $3N$ dimensional space, instantiating its own intrinsic properties of phase and amplitude, and there are particles inhabiting a distinct three dimensional space that are fundamentally attributed nothing but positions in that space.

There are a couple of things that need to be noted about this view, and its putative consequences for the constitution of people, tables, chairs, and the other inhabitants of what we think of as our physical world. First, Bohmian mechanics is only one of several promising approaches to quantum mechanics. Although it does seem plausible to take it to motivate this kind of two-world, two-kind-of-entity ontology, on nearly all other realist approaches to quantum mechanics, particles are typically regarded as nonfundamental and reducible to elements of the wavefunction, not separate entities in a separate space. This kind of one-world picture of quantum mechanics is elaborated by David Albert (1996) and Peter Lewis (2004) with respect to collapse approaches for quantum mechanics, and David Wallace (2003) who endorses an Everettian no-collapse

view. If one thinks everything reduces to the wavefunction, then the physical world is the world of the wavefunction. There is no separate three dimensional space. The only space that exists is $3N$ dimensional and does contain instantiations of fundamental intrinsic properties. So in particular, people like you and I, tables, chairs, and planets are all constituted fundamentally by an entity (the wavefunction) instantiating intrinsic properties.

There are many reasons to prefer this latter picture, as opposed to the “two world” picture in which the wavefunction is a separate, wholly distinct entity from the particles that make up physical objects. There is, as always in matters of ontology, the pull from Ockham’s razor to reduce, in this case reduce the particle ontology to the wavefunction. However, a more relevant consideration for our purposes arises from the fact that even on a two-world picture like the one that seems implied by Bohmian mechanics, the properties of physical objects like people, tables, and chairs, those properties that seem to make these objects what they are, are all ultimately grounded in the properties of the wavefunction, not the properties of the particles in the three dimensional space. Even on a picture in which particles are separate from the wavefunction, it is states of the wavefunction that determine their behavior over time.¹⁹ The particles only have positions; they have no other causally relevant features. So, all causal features you or I have constituting our ability to affect the world, that is, do what it is that we do, are ultimately grounded in features of the wavefunction, not in any basic features of the

¹⁹ In Bohmian mechanics, there are two fundamental laws: the Schrödinger equation that describes the evolution of wavefunction as a function of its prior state, and the guidance equation that describes the evolution of the particle positions as a function of the prior state of the wavefunction. There is no fundamental law describing the evolution of anything as a function of earlier states of the particles (Goldstein 2006).

particles, i.e. their positions. As a result, there does not seem to be any legitimate sense in which one can accept the wavefunction ontology of quantum mechanics and yet still maintain that the physical world of which you and I are members is a world lacking in fundamental intrinsic properties. Even if what we perceive as the physical world is not ultimately constituted (in a mereological sense of ‘constituted’) by the instantiation of intrinsic properties, its entire character results from the instantiation of intrinsic properties. So, it is false that quantum mechanics gives us reason to reject that intuitive picture according to which the physical world fundamentally involves the instantiation of intrinsic properties.

4. Conclusion

In this paper, I have tried to show that despite an interesting argument to the contrary, at least some properties of fundamental physics are intrinsic. And these are indeed the properties that ground the causal powers of material objects in our world. Thus, we have no reason at this time to fear that we cannot know the intrinsic natures of things, how they are in themselves.

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