Chapter 10
Quantum Holism and Essential Dispositions

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Abstract It is often suggested that at least some entities posited in QM are non-individuals, in the sense that they are numerically distinct entities but there is no fact of the matter as to which entity is which. Such entities are often regarded as holistic, in the sense that they necessarily belong to some larger system (for instance, each member of a pair of entangled electrons necessarily belongs to that system). The metaphysics of holism has been developed in different ways, e.g., relational holism (Teller, Br. J. Philos. Sci. 37:71–81, 1986; Morganti, Philos. Sci. 76:1027–1038, 2009), priority monism (Schaffer, 2010a; Ismael and Schaffer, Synthese 197:4131–4160, 2020) and OSR (Ladyman and Ross, Every thing must go: Metaphysics naturalized. Oxford University Press, Oxford, 2007; Esfeld and Lam, Synthese 160:27–46, 2008; French, 2014).

In this paper, we shall outline a metaphysical model of holism which has not yet been developed in detail, in terms of mutual essential dependence. Roughly speaking, two entities are mutually essentially dependent if the essence of each entity, i.e., what that entity is, involves the other entity. This form of dependence can hold between individuals or between non-individuals. It is thus an ideal way to understand the holism of non-individuals in QM.

We shall argue that this model of holism applies to a number of topics in QM and particle physics. We shall also argue that this model provides a better account of quantum holism than the priority monism recently championed by Ismael & Schaffer.

Keywords Ontological dependence · Grounding · Common ground · Entanglement · Coherentism

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A well-known feature of entangled quantum systems is *non-supervenience*: states of the system as a whole do not supervene on the non-relational states of its component particles.[1] For example, consider two electrons in a nonseparably entangled quantum state like those found in the lowest orbital of the helium atom.[2] In this case the entire system has a property—*having electrons with opposite x-spin*—even before the x-spin of the electrons is measured; however, none of the components of the system has a determinate x-spin before the x-spin is measured. So there is a property of the system as a whole which does not supervene on the properties of its components (either considered separately or considered together).[3]

Non-supervenience has led to a number of different metaphysical developments including what one might call the "historical holistic view" (Shimony, 1978; Teller, 1986; Healey, 1991), relational holism (Teller, 1986; Morganti, 2009), versions of structural realism (Ladyman, 1998; French & Ladyman, 2003; Esfeld, 2003, 2004; Ladyman and Ross, 2007; Esfeld & Lam, 2008, 2010; French, 2010), and priority monism (Schaffer, 2010a; Ismael & Schaffer, 2020).

In this paper we shall outline an account of one crucial non-supervenient feature of entangled systems, the fact that entangled particles are *modally connected* (so that it is not possible to freely vary all of the features of one without varying some features of the others). In Sect. 10.1, we shall outline the sense in which entangled quantum particles are modally connected, and the monistic account of this modal connection proposed by Jenann Ismael and Jonathan Schaffer. In Sect. 10.2 we outline an alternative approach, on which the modal connection is explained by appeal to the essences or natures of the entangled particles. We outline one way in which this approach can be developed, which we term the Straightforward Proposal, and argue that it does not work. In Sect. 10.3 we introduce our preferred way of developing this approach, the Essential Disposition account, which we suggest is a holistic account of a specific kind (essential holism) In Sect. 10.4 we compare our account with that offered by Ismael and Schaffer, assessing each account on a number of different criteria. In the course of this discussion, we shall clarify how our account is neutral as regards the individuality or non-individuality of quantum particles: that is, it applies equally whether or not entangled particles are individuals.

[1] We assume that a *state* of an entity or entities (e.g., a system, certain particles, etc.) is the instantiation by that entity or entities of one or more properties, where these properties can include relations.

[2] Philosophers and physicists have used the term "nonseparability" in a number of different ways (Healey, 2016). Ismael and Schaffer, following Healey's notion of spatial nonseparability, put it nicely: "Entities a and b are nonseparable if and only if fixing the intrinsic state of a, the intrinsic state of b, and the spatial relations between a and b fails to fix the intrinsic state of $a + b$" (2020, 4145).

[3] See Calosi and Morganti (2021) for a good discussion of the kind of entanglement in which we're interested. In their terms, it's the kind of entanglement that "gives rise to non-local correlations violating some form of Bell-inequality" (867). The singlet state that we will use as an example does this.

10.1 Quantum Mechanics and Holism: Some Choices

The strong non-supervenience of quantum systems can be understood in any of a number of different ways, depending on one's metaphysical assumptions. Paul Teller outlines *relational holism*, in which at least some entities posited in QM (e.g., entangled particles) are the relata of relations which do not supervene on the non-relational properties of those entities.[4] For example,

> We consider two particles with the non-classical property of spin, and we construct a certain simple superposition of two non-relational spin states of *a* and of *b*. In this superposition quantum mechanics does not assign a definite spin to either particle in any direction, and [. . .] even if one postulates specific spins for particles in the superimposed state, the property described by the superposition does not supervene on the postulated individual properties (Teller, 1986, 79–80).[5]

An alternative position can be termed *non-relational holism*. On this view, it is not non-supervening relations which explain the failure of supervenience, but rather properties of the system as a whole (Morganti, 2009, 1031). On the face of it, relational and non-relational holism do not seem to be radically different. They both take the fact that entangled systems can be understood to be nonseparable and argue that this leads to a holistic metaphysics. But the most prominent version of non-relational holism is actually quite different from relational holism; this is the *monism* defended by Ismael and Schaffer (2020, see also Schaffer, 2010a, 51–55).

A crucial part of Ismael and Schaffer's argument is the following claim: by belonging to an entangled system, entangled particles, such as those with opposite directions of spin, are *modally connected* (2020, 4146).[6] Roughly speaking, numerically distinct entities x and y are modally connected if there are some metaphysically possible states of *x (S1x, S2x, . . .)* and some possible states of *y (S1y, S2y, . . .)* such that, necessarily, the specific state *x* is in will exclude the possibility of *y* occupying certain states, and vice-versa.[7] For instance, if *x* and *y* are overlapping circles, then whatever colour *x* is will constrain the colours which *y* could be; if *x* is wholly blue, then *y* cannot be wholly any colour other than blue (ibid., 4136). If *x* and *y* were not modally connected, then it would be possible to *freely combine x* and *y*,

[4] These relations are not spatiotemporal relations between the particles; they can be understood as entanglement relations, or as relations which give rise to entanglement.

[5] By "the property described by the superposition", Teller means the relation holding between the entangled particles.

[6] The characterisation of modal connections which follows is rather sketchy, but it is adequate to present the idea as found in Ismael and Schaffer (2020). For a more detailed presentation see Schaffer 2010b, 348–355. In that paper Schaffer uses the terminology of a modally constraining relation, "a relation that precludes the free recombination of its relata" (350); for critical discussion of this idea, see Wang (2016) and Zimmerman (2015).

[7] It is not entirely clear what the strength of the modal terms here is supposed to be. For the moment we assume that they should be read as expressing metaphysical modality; in Footnote 21 we shall briefly consider how our account could work if the modal connections held with nomological strength.

in the following sense: it would be metaphysically possible for *x* to be in any of *S1x, S2x, …* and for *y* to be in any of *S1y, S2y, …* That is, the specific state *x* is in would in no way limit which states y could be in, and vice-versa. In the example of two electrons entangled with respect to spin properties, if *x* is measured as having spin-up, then necessarily *y* will have spin-down (ibid., 4142). Thus, *x* and *y* cannot be freely recombined with respect to their spin properties—these properties cannot vary independently of each other, so *x* and *y* are modally connected with respect to their spin properties.

Generally speaking, we should look for explanations for modal connections. In some cases, they can be explained causally (e.g., if entities *x* and *y* are modally connected, this may be because *x* causes *y*, or *y* causes *x*, or both *x* and *y* have a common cause). However, Ismael and Schaffer argue that this approach cannot work in the case of quantum entanglement (2020, 4134). The alternative which they consider is that distinct entangled particles *x* and *y* are *ground-connected*: that is, either *x* grounds *y*, or *y* grounds *x*, or *x* and *y* have a common ground. It is the last of these options which Ismael and Schaffer officially adopt. Their argument can be seen as an *inference to a common ground*:

> One starts with some collection of entities for which there may at first be no recognized connections […]. One then uses modal constraints on mutual variation [i.e., modal connections between the entities] to reveal that some of these entities are not entirely distinct existences, but in fact involve some underlying shared portion of reality [i.e., the common ground] (2020, 4136–7).[8]

More generally,

> All else being equal, in the kind of epistemic setting in which we have no direct access to the grounding substructure of a collection of objects, a theory that explains constraints on their modal covariation by reference to a common ground is better than one that regards it as a brute modal connection between distinct existences (op. cit., 4139).[9]

Ismael and Schaffer argue that the best explanation for modal connections between entangled particles is that they share a common ground, that is, the system to which they each belong (2020, 4148–4150). Therefore, unlike with relational holism, on monism each entangled system is ontologically and explanatorily prior to its parts. Furthermore, Ismael and Schaffer argue that the physical universe as a whole is a single entangled system which is prior to any of the physical entities it includes as parts (2020, 4150ff.). So while relational holism is compatible with entangled particles themselves being metaphysically fundamental entities, monism rules this out.

[8] We shall return to Ismael and Schaffer's discussion of 'entirely distinct existences' in section 5 below.

[9] Ismael and Schaffer outline grounding as "a metaphysical relation characterizing the connection from the more to the less fundamental entities" (2020, 4135). It is an asymmetrical relation which underwrites metaphysical explanations, in much the same way that relations of causation underwrite causal explanation.

In what follows, we accept that entangled particles are modally connected. Furthermore, we accept Ismael and Schaffer's working assumption that in general modal connections stand in need of explanation. It might be that some such connections are brute, but we think it is theoretically more promising to at least search for a possible explanation of any such connection. Our disagreement with Ismael and Schaffer concerns how best to explain modal connections between entangled particles. Ismael and Schaffer claim that these particles are all grounded in the entangled systems to which they belong (and ultimately on the cosmos as a single entangled system): they are "derivative *aspects* (or *fragments*) abstracted from a more fundamental whole" (2020, 4149).

We suggest, instead, that the modal connections between entangled particles are grounded in the essences of these particles. As we shall outline, this interpretation allows for a metaphysical model which does not require that entangled systems are ontologically prior to the particles they include. Furthermore, this view is compatible with them being either (dependent) individuals or non-individuals.[10]

10.2 The Straightforward Proposal

A popular trend in modal metaphysics has been to explain why certain necessities hold by appealing to the essences of certain entities (a trend initiated by Fine 1994 and developed, e.g., by Hale 2013).[11] We propose to explain the modal connection between entangled particles in this way. In particular, we shall appeal to the *general essence* of entangled particles. As E.J. Lowe puts it, "if X is something of kind K, then we may say that X's general essence is what it is to be a K, while X's individual essence is what it is to be the individual of kind K that X is, as opposed to any other individual of that kind" (2008, 35).

What is essentially true of an entity, x, can be stated in true predicative statements of the form 'x is essentially F'. These statements will state x's *general* essence if they do not state which entity of its kind x is. For example, suppose that c is an individual cat. One may think that it is essential to c to be a member of the family *Felidae*; that is, it is part of what it is for that very entity to exist that it be a member

[10] It is worth noting that the relational holism defended by Teller (1986) and more recently by Darby (2012) and Calosi (2014) does not explicitly account for the modal connection between entangled particles. To say that entangled particles are modally connected because external entanglement relations hold between them invites the question of why these relations hold.

[11] The exact relations between grounding and essence are the subject of much recent discussion (for an overview see Rydéhn 2021). We shall not examine this issue in detail. For our purposes what matters is that the kind of essential conditions we suggest hold for entangled particles are clearly different from grounding as conceived of by Ismael and Schaffer, for at least three reasons. First, unlike grounding, the essential conditions we shall consider can be symmetrical; second, unlike grounding, these essential conditions can hold between fundamental entities; and third, unlike grounding as conceived by Ismael and Schaffer, these conditions are not themselves relations.

of this family. If this is correct, then it is plausibly part of c's general essence that it belongs to this family, because it is true of any cat that it is essentially a member of this family. It may also be essentially true of c, this specific entity, that it originates from some specific gametes and hence has a specific history. If this is an essential truth about c, it is part of c's individual rather than general essence, since it is not essential to cats in general that they originate from those specific gametes.[12]

Our proposal, then, is to explain why entangled particles are modally connected by appealing to the general essence of these particles (roughly, what it is to be a particle of that kind, e.g., what it is to be an electron, etc). However, before stating our own proposal it is worth considering an alternative way in which one might try to explain modal connections between numerically distinct entities by appealing to what is essential to one or the other of these entities, or what is collectively essential to all of these entities. Considering some of the drawbacks of this proposal will allow us to better frame our own explanation.

The alternative explanation is what we shall term the *Straightforward Proposal*: x and y are modally connected with respect to property F (e.g., direction of spin) because it is collectively essential to x and y that if one is $F1$ (i.e., spin-up), the other must be $F2$ (i.e., spin-down).[13]

This explanation relies crucially on a claim about what is *collectively essential* to x and y. How can this claim about what is collectively essential to x and y be understood? Calosi and Morganti (2021, 868) offer the following proposal, which we shall term Mutual Essential Dependence:

Mutual Essential Dependence (MED) : x is essentially such that $Ex \rightarrow Ey$ & y is essentially such that $Ey \rightarrow Ex$.

In MED, 'E' is the existence predicate, but Calosi and Morganti note that what they are really concerned with is not just the existence of electron x or electron y, but each electron's existing and having certain properties (e.g., a certain direction of spin). As they put it, "ontological dependence is the relation whereby something x depends on something y for its existence and its properties" (2021, 869; see also 882). So insofar as MED is applied to entanglement, 'Ex' and 'Ey' can be understood as including, e.g., x or y's having spin-properties.[14]

[12] General essence is a species of *objectual essence*; that is, it is part of the essence of some entity or entities. This contrasts with *generic essence*, which for any predicate F is the essence of F-ing (Correia, 2006, 754). We shall not discuss in detail the differences between general essence and generic essence, except to note that generic essence is *not* to be understood as a species of objectual essence: that is, the essence of F-ing, for any predicate F, is not the essence of some entity x which F picks out (see in particular Correia, 2006, 760–763).

[13] For ease of presentation we shall characterise both the Straightforward Proposal and our own preferred account in terms of electrons with different directions of spin. However, it is important to note that each account is intended to apply to a variety of entangled particles and different properties of these particles.

[14] It is also important to note that the dependence in MED is *rigid*; that is, x's being E is dependent on a specific particle y's being E, and not on any other particle's being E (Calosi & Morganti, 2021, 868; 875–876).

The Straightforward Proposal, then, is that x and y are modally connected when they are entangled because when entangled they satisfy MED.[15]

To make clear the problem with the Straightforward Proposal, note that the rigid modal connection between the specific entities x and y only holds once they are entangled with each other. This point is acknowledged by Calosi and Morganti; they note that MED does not require "that the two particles are mutually dependent in general, as they may well exist unentangled. The claim is that once they interact in certain ways, they become symmetrically dependent on one another" (2021, 882). But if it is the case that x and y are rigidly connected only when entangled with each other, then MED, at least as applied to entangled particles, is a *conditional essential connection* between x and y. That is, an essential truth about x (i.e., that $Ex \rightarrow Ey$) holds only given a certain condition, i.e., that x is entangled with y. Furthermore, this condition is itself plausibly contingent. Calosi and Morganti themselves accept that the two particles "may well exist unentangled" (2021, 882). And it is widely thought that particles which are entangled can cease to be entangled and yet survive.

The idea of conditional essential truths, and particularly of contingent essential truths, is very dubious (setting aside the issue of whether essential truths about x can obtain if x does not exist). The suggestion is that a truth p could be essentially true of x at time $t1$ and yet p could be false at a different time, $t2$; or p could be essentially true of x under certain contingent circumstances and yet fail to be true of x under different possible circumstances. This goes squarely against the widely accepted view that essential truths are metaphysically necessary. An essential truth about x states, in part, what it is to be x; an essential truth about a kind K states, in part, what it is for any entity to be a member of K, i.e., to be one of the Ks. It makes little sense to think that an entity could, e.g., count as one of the Ks despite not satisfying what it is (even in part) to be one of the Ks.[16]

For this reason we think that the Straightforward Proposal should not be accepted. Nevertheless, we do wish to explain the modal connection between entangled particles by appealing to the essence of these particles. But to do this, we need to reject MED and rethink the role played by the essence of each particle.

[15] It is not entirely clear if Calosi and Morganti would endorse the Straightforward Proposal as we have stated it here. However, their discussions of how the coherentist can account for correlations violating Bell inequalities (2021, 885) and the difference between completely and non-completely entangled systems (op. cit., 886) certainly can be read as applications of this proposal.

[16] In applying MED to entangled particles, we assume that the terms 'x' and 'y' apply to particles of specific kinds, e.g., *electron*. On this reading, the Straightforward Proposal is an account of why entities of these kinds become modally connected when entangled with each other; as such, it is vulnerable to the objection just outlined because being entangled is, plausibly, not an essential feature of any electron. An alternative reading of MED would take the relevant kind to be, not *electron*, but *entangled electron*. On this reading, the above objection would not apply, since if there is a kind *entangled electron*, it is plausibly essential to members of this kind that they be entangled (thanks to Claudio Calosi for pointing out this reading). We shall not discuss this suggestion in much detail, beyond noting that if *entangled electron* is a fundamental kind of entity, it would seem to require that electrons change kind when they become entangled. On our preferred view, becoming entangled is something electrons are capable of doing, and this does not change the fundamental kind to which they belong.

10.3 The Essential Dispositional Account

The idea we wish to propose is as follows: each electron is essentially such that, should a certain condition be met, that electron would be modally connected (with respect to some property or properties) with another electron (or electrons).[17] More generally, it is essential to particles of the kind fermion that they can enter into entanglement relations with other fermions with respect to several of their properties (degrees of freedom).

The intuitive idea can be put as follows: each electron essentially has a number of 'slots' which can be filled by some other electrons, and each electron is essentially such that it will enter into a rigid modal connection with whatever electron actually fills one of its slots.[18] To be more precise, each electron essentially has a 'slot' with respect to each of its degrees of freedom. These slots can be matched by another electron's equivalent slot. Furthermore, the slots do not have a determinate adicity, as entanglement is not always bipartite like in the case of spin properties.[19]

This intuitive idea leaves open the precise metaphysical picture which holds. We think it is possible to develop this picture in a number of different ways, depending on one's overall theoretical inclinations. In what follows, we shall develop it in terms of each electron's essentially having certain dispositions. However, it is important to note that it is not obligatory to understand the intuitive idea in this way (i.e., to commit to a metaphysics of dispositions).

Let x be any electron. For x to be in condition C is for x to be entangled with n other electrons, where $n \geq 1$ (the other electrons are *y1, y2,*...).[20] The essential disposition of x is as follows:

Essential Disposition (ED): any electron, x, essentially has the disposition to become modally connected (with respect to some property or properties) with an electron or electrons ($y1$, or $y2$, ...) when condition C obtains for x.

To clarify ED, it is worth noting the following points. First, this essential disposition is *general*, in that it is essentially true of *any* electron—it is part of what it is for something to be an electron that it is disposed to enter into modal connections with other electrons. So ED holds for each of $y1$, $y2$, etc., as well as for x.

[17] An acute reader will notice that there is an element of conditionality in this proposal as well. However, as we shall presently explain, our proposal does not have the same problem with this as the Straightforward Proposal faces.

[18] The metaphor of 'slots' has been used in other metaphysical discussions, e.g., to characterise relations as having certain numbers of argument places (see Gilmore, 2013).

[19] While we focus on entanglement between electrons, it is worth noting that our approach can in principle work with regard to any degree of freedom (so any property) of any entity. We shall presently outline a generalised version of our position, but for the moment we shall continue to work with the example of electrons.

[20] Though see below for an important clarification of what it is for x to be in C.

Second, what is essential to x is *not* that it is modally connected with any other electron or electrons (e.g., *y1, y2*, etc.). Rather, what is essential to x is that it has a certain disposition to *become* modally connected with other electrons (when condition C obtains for x). More generally, ED does not entail that x is essentially *connected* or *related* with any other entities. It is widely accepted that dispositions need not be relational, in the sense of requiring their bearer to stand in certain specific relations; indeed, for all ED says, it can hold of x even if none of the Ys exist. Nor does ED entail that x essentially depends upon any of *y1, y2*, etc., if essential dependence is taken to require the existence of the entities depended upon.

Third, this disposition is a *generic disposition*, in that it is not a disposition for x to be connected with any other electron in particular (say, to $y1$ as opposed to $y2$). Rather, it is a disposition directed at any electron whatsoever. But once x stands in condition C with some other electron or electrons, then it is with that very electron or those very electrons that x will be modally connected.

Fourth, this essential disposition is *unconditional*: it characterises each electron regardless of whether or not the electron is entangled, or ever has been entangled. In contrast, the modal connection of entangled electrons x and y is *rigid* and *conditional*. Because of these features of this modal connection, it is not plausible that the modal connection between x and y is itself essential to x, to y or to x and y collectively. Our proposal is to explain this rigid, conditional connection in terms of an essential disposition which is generic and unconditional.[21]

It may be worth noting here that while ED does bear a similarity to MED from the previous section, there are important differences. In particular, once we acknowledge the possibility that an electron never becomes entangled, then we need, in any case, some way to account for the possibility that particles *may* become entangled. This is an additional essential fact and we suggest that, far from being negligible, it should be at the core of a metaphysical account of entanglement.

In formulating ED we referred to condition C, which we glossed as x's being entangled with some other electron or electrons. It is worth noting that we can leave open what exactly this condition itself consists in. We think that characterising the conditions under which two particles are entangled is a matter for empirical investigation. What we are trying to explain is what it is about these particles (their general essence) which enable them to become modally connected when those empirically-specifiable conditions are met.

As stated, ED is a claim about the nature of electrons. However, entities other than electrons can become modally connected. Therefore, it is worth stating a more general version of ED, one which leaves open the kinds of entity to which it applies.

[21] We are interpreting the modal connection between entangled particles, for which ED provides an account, as metaphysical in nature. However, as noted above (Footnote 7) ED can be interpreted in a way which is compatible with the modal connection being nomological rather than metaphysical. On this reading, ED would in effect be the claim that to be an electron is (in part) to obey the laws of QM. This is compatible with these laws being metaphysically contingent: in a world where they do not hold there would be no electrons (thanks to Claudio Calosi for bringing this point to our attention.).

Generalised Essential Disposition (GED) : any entity of kind K essentially has the disposition to become modally connected (with respect to some property or properties) with an entity or entities of kind L, when condition C obtains for that K.

In GED, 'K' stands for any kind whose members can become modally connected with other entities. 'L' stands for whichever kind members of which can become entangled with Ks (note that the Ls might themselves be Ks, as in ED where electrons can become entangled with other electrons).

To illustrate how our account generalises beyond the relatively simple example of two entangled particles with opposing spin, we shall consider another example from particle physics. The Standard Model of particle physics treats quarks as point-like particles that have no internal structure; they are mereological atoms. But quarks do not exist independently; they come in groups of two or three, such as in the case of mesons, protons, and neutrons. This invites the question whether the three quarks that compose a proton, for instance, are modally connected in the sense in which we are interested. There is at least a clear causal connection between these quarks: the strong bond between quarks is known as *quark confinement*, and it is sometimes illustrated with the 'bag model'. The idea is to think of a quark triplet as if it was inside a stretchy bag. If you then try to separate one of the quarks in the triplet, you'll discover that the bag resists your efforts with an increasing force. The energy that would be required to isolate a quark from the triplet is far greater than the pair production energy of a quark-antiquark pair. What happens is that before the isolation could happen, the energy being directed to the process produces mesons—quark-antiquark pairs. Instead of pulling apart a quark from a quark triplet you end up with a quark-antiquark pair (and the original quark triplet remains intact).

One way to interpret this would be to think of each of the quarks as dependent on, or grounded in, the proton to which they belong. This line of thought would follow that proposed by Ismael and Schaffer for entangled electrons: the proton would be a common ground for each of the quarks in the triplet. However, it is possible to interpret this in a different way, following our proposal above. In this case, each of the quarks, *x, y, z*, in the quark triplet may be considered to essentially have the disposition to become modally connected with two other quarks. Once condition C obtains, they become mutually dependent on each other (rather than on the proton that they compose, in contrast with the common ground interpretation). It is important to notice that now condition C is very different from the case of entanglement; in the quark triplet case it can, perhaps, be considered as the requirement that the three quarks compose a further entity, such as a proton. But even if one does not wish to make a commitment to protons as a genuine novel entity, condition C would still be different from the case of entanglement, since the interaction of the quarks is governed by *strong interaction*, which has a very short range. This reading of quark confinement is certainly not uncontroversial, but it is coherent and may help us understand how seemingly independent fundamental particles can become modally connected. The proposal is that they can do so because they are essentially disposed to become modally connected.

Our proposal is a form of holism, but of a quite specific kind. First, it is necessary to distinguish between what we term existential holism and essential holism. *Existential holism*, as the title suggests, is a condition on the existence of members of a certain kind, the *K*s; for instance, it might be that each individual *K* can only exist in a network of other *K*s, or only when suitably related to some members of another kind, the *L*s, etc. *Essential holism* is a condition on what it is to be a *K*, rather than on any *K*'s existing (or on a *K*'s having a certain property). The basic idea is that the general essence of *K*s, what it is to be a *K*, itself includes other entities, the ones which would be named in a statement of the general essence of *K*. So if each *K* is essentially such that it is disposed in condition *C* to become entangled with an *L*, then the essence of *K*s will include *C* and *L*s. However (and this is the crucial difference between existential and essential holism) this kind of holism does not require that the entities included in the essence of *K*'s actually exist. That is, in stating what it is to be a *K* we can appeal to types of entities, without any entity of that type actually existing.[22]

To illustrate the idea, consider a toy example of a disposition, e.g., solubility. We can state the essence of solubility; it is (roughly) a disposition of an entity to dissolve if placed in a liquid. This statement of the essence of solubility appeals to liquids, but it does not follow from this statement that we are thereby committed to there being liquids. It seems possible for an entity to be soluble if it exists in a universe containing no liquids whatsoever.[23] Similarly, suppose that what it is to be a *K* is, in part, to have the capacity to become entangled with an *L*. On our conception, *K*s could exist even if there were no *L*s; in that scenario, each *K* would still by its nature be apt to become entangled with an *L*.

This position can be thought of as holistic in two respects. First, each *K* is by its nature apt to enter into specific combinations (i.e., become entangled) with other entities. One might say that *K*s are *holistically inclined*; they are essentially susceptible to entanglement. Note that this holism, or holistic inclination, is built into the *general* essence of *K*s. It is characteristic of *K*s as a type that they are apt to become entangled. This contrasts with Calosi and Morganti, who say that "for the coherentist it is always specific entangled system-tokens that come first, in the order of explanation and at the metaphysical level" (2021, 884). Of course, it is specific particles which become mutually dependent on each other; where we disagree with

[22] It is worth noting that existential holism can be grounded in the essences of the entities involved: i.e., it might be part of the general essence of *K*s that a *K* can exist only if suitably related to some *L*s, etc. Let us term this *essential existential holism* (inspired by the notion of essential existential dependence—see Tahko and Lowe, 2025, §4.3). The difference between essential existential holism and essential holism is that the former entails a specific kind of condition on the existence of any *K* (a *K* can exist only if certain entities mentioned in a statement of its essence exist); the latter does not entail this kind of condition.

[23] It is crucial to clarify that this statement of the essence of solubility does not mention any specific body of liquid. Rather, it is liquids as a type (or perhaps certain kinds of liquids) which can feature in its essence. Similarly, our characterisation of essential holism does not require that any individual entities feature in the essences of the *K*s.

Calosi and Morganti is that we claim that the general essence of the particles is explanatorily prior to any particular entangled system, at least in terms of providing a metaphysical account of the modal connection between entangled particles.

The second respect in which our position is holistic is much more speculative. The way we state the general essence of Ks in GED leaves open with which types of entities and in which respects (i.e., with regard to which properties or degrees of freedom) each K can become entangled. As we have stated it, it is in principle possible that any K can become entangled with any other entity with respect to any of its properties (i.e., in GED the term 'Ls' is really a placeholder). If one takes this possibility seriously, then the nature of Ks would seem to be *radically holistic*, in that they would be apt to be combined with any other entity whatsoever. Indeed, one could go further: it might be that any entity of whatever kind is apt to become entangled, in the right circumstances. Of course, it is important to note that the general essence of Ks does not require this outcome—and we do not intend to commit to such radical holism. In fact, which entities can become entangled, which entities a K can become entangled with, and in which respects, are largely to be decided empirically.

10.4 Essential Connectedness and Grounding: Comparing the Accounts

Ismael and Schaffer argue that where we find modal connections, we should look for an explanation; and in the case of entangled particles, they propose that the best explanation for their modal connection is an inference to a common ground.[24] We accept the need for an explanation, but deny that an inference to a common ground is thereby justified. We have outlined an alternative explanation of the modal connection which appeals to the essences of the entangled particles.

Our explanation is an alternative to Ismael and Schaffer's, but is it better? How one evaluates this question will to a large extent depend on the background commitments one brings to it. What we claim is that given independently plausible assumptions, our proposed explanation has advantages over an inference to a common ground. The most important of these advantages is that is that our approach leaves open the possibility of some particles being metaphysically fundamental (e.g., they are not grounded in or asymmetrically dependent upon anything else), as opposed to the cosmos as a whole being the only fundamental entity, as with monism. There are interpretations of quantum mechanics, such as Bohmian mechanics, that postulate particles as fundamental entities, so our approach would be compatible with these *pluralist* interpretations. This is a theoretical advantage because our approach can accommodate *both* a monist and a pluralist ontology.

[24] Similarly, Schaffer argues for priority monism as a way of explaining the internal relatedness (i.e., the modal connectedness) of all things (2010b).

In a little more detail, consider what Goldstein (2017, §4) writes about Bohmian mechanics:

> In the Bohmian mechanical version of nonrelativistic quantum theory, quantum mechanics is fundamentally about the behavior of particles; the particles are described by their positions, and Bohmian mechanics prescribes how these change with time. In this sense, for Bohmian mechanics the particles are primary, or primitive, while the wave function is secondary, or derivative.

Here, 'fundamentally' seems to be used in the sense that the fundamental *entities*, according to the Bohmian interpretation, are the particles. This is in line with a fairly common sense of fundamentality (sometimes called *mereological fundamentality*, see Tahko, 2023). Accordingly, the entities that are fundamental according to the Bohmian theory are good candidates for being metaphysically fundamental as well.

Developing the above line of reasoning, we may consider how well the different metaphysical accounts line up with the available interpretations of QM. Calosi (2018) argues that monism does not fit well with a number of well-known interpretations, including modal interpretations (§3.1) and Bohmian mechanics (§3.2). Nor does it fit comfortably with Rovelli's relational QM (Dorato, 2016). It would be too quick to conclude that our position is the best metaphysical account of QM under these interpretations. But it is undeniable that each of these interpretations either requires or is at least compatible with there being multiple fundamental entities. If entangled particles are among the fundamental entities, then our position is a more plausible metaphysical model for these interpretations. On this approach, unlike that proposed by Ismael and Schaffer, entangled particles can be metaphysically fundamental entities.[25]

Another point concerns the implications of the two accounts for the individuality or non-individuality of entangled particles. There are different senses in which entities can be thought of as individuals, and correspondingly different senses in which they can be regarded as non-individuals. An entity might count as an individual if it is *absolutely discernible* from all other entities; correlatively, none of a number of entities would be individuals, on this view, if they were not absolutely discernible from each other.[26] Alternatively, Simon Saunders and F. A Muller have argued that individuals only need be *weakly discernible* from each other, that is that they stand in an irreflexive relation to one another.[27] On a third view, championed by Lowe (e.g., 1998), an entity is an individual if there is a fact of the matter as to

[25] There are other interpretations of QM which are more holistic, e.g., Everettian interpretations and wavefunction realism. How our position would accommodate other interpretations of QM, and how it would compare with Ismael and Schaffer's position regarding these other interpretations, are questions worth exploring in further work.

[26] Two objects are "absolutely discernible" iff it is the case that one of them has a property that the other lacks (see Saunders, 2006; Muller and Saunders, 2008; Muller and Seevink, 2009 and Bigaj, 2015).

[27] See in particular, Saunders 2003, Saunders 2006, and Muller and Saunders 2008; see Dieks and Versteegh 2008 for criticism.

which entity of its kind it is, and entities fail to be individuals if there is no fact of the matter as to which is which.[28]

There are competing views as to whether quantum particles are individuals or non-individuals, and concerning each of these views there is the further question as to which understanding of individuality is at stake. In light of these theoretical disputes, we suggest that it is a desideratum of a metaphysical theory of entanglement to remain neutral on whether or not quantum particles are individuals, on any of these understandings of individuality.

Since our account is pitched in terms of the general essence of particles, and since this does not seem to require that the entities which share such an essence are individuals in any specific sense, then our account is applicable to entangled particles whether or not they are individuals. For instance, in the statement of ED, it is not required that there be any fact of the matter as to which electrons *x, y1, y2*, etc. are; all that is required is that they are numerically distinct from each other. Therefore, ED is compatible with electrons being either individuals or non-individuals, on Lowe's (1998, 197) account of individuality. Furthermore, our account does not require that entangled particles must be absolutely discernible (from each other, at least); again, ED is compatible with none of these electrons having any non-relational properties which any of the others lack. So even if individuals were to be understood as absolutely discernible entities, our account applies to individuals or non-individuals in this sense as well. That is, our account is neutral as to whether entangled particles are individuals or non-individuals, on both of these senses, and in this regard the theory is on par with other metaphysical accounts of entanglement.

10.5 Hume's Inference

Finally, it is worth considering a possible objection to our account which might be offered by Ismael and Schaffer. They assume *Hume's Inference*: if entities x and y are necessarily connected, then x and y are not distinct existences (2020, 4138; see also Schaffer, 2010a, 40; 2010b, 350). The notion of entities being distinct from

[28] As we understand it, Lowe does not propose that individuality is a matter of there being a *haecceity*. Rather, the individuality is primitive. But either way, our account can capture this type of view. A final caveat that remains is whether our account can be neutral if individuality is understood in terms of weak discernibility, since, it might be thought, if two particles x and y are entangled with each other, they each stand in an irreflexive relation with the other; and this is enough for them to count as individuals, if individuality is understood in terms of weak discernibility. But the understanding of individuality in terms of weak discernibility is itself open to objection, at least if we limit ourselves to considering qualitative properties (see Lowe, 2015). Moreover, if individuality is understood in terms of weak discernibility, then it is arguable that every account of entangled particles must treat them as individuals. In fact, Ladyman (2015) has suggested that the distinction between weak and absolute discernibility may not allow for a good understanding of individuality in physics at all.

each other in this context does not simply mean that they are numerically distinct. To capture the relevant kind of distinction, let us refer to 'distinct existences' in the context of Hume's Inference as being *wholly distinct entities*.[29] Ismael and Schaffer suggest a "metaphysical reading" of the notion of being, as we put it, wholly distinct: entity x and entity y are wholly distinct if x and y "are neither identical nor connected by grounding (neither grounds the other, nor do they have a common ground)" (2020, 4138). On this reading, if x and y are modally connected, then either x is identical with y, or one grounds the other, or they have a common ground.[30]

If Hume's Inference and the proposed definition of wholly distinct entities is assumed, this creates a problem for our account. If electron x and electron y are entangled and so modally connected with each other, then they cannot be wholly distinct from each other. Nor can they be identical, so either x grounds y, or y grounds x, or they have a common ground. Any of these proposals threatens to make our account redundant, by providing an alternative account of the modal connection of x and y.

This problem only arises, however, if Hume's Inference and the proposed definition of wholly distinct entities are both accepted—but what reason is there to accept either? Start with the latter: why accept that x and y are *not* wholly distinct *only* if they are identical or connected by grounding? 'Being wholly distinct' is a term of art rather than a term with a fixed prior meaning. So it is open to us to suggest that x and y might fail to be wholly distinct if, for instance, they are essentially connected along the lines of MED (Sect. 10.2). Being essentially connected in this way does not, we claim, entail that x and y are connected by grounding. Therefore, Ismael and Schaffer's proposed definition of wholly distinct entities may not be adequate.[31]

Uncontroversial examples of mutual essential connections are hard to find. Nevertheless, the idea can be made more familiar by considering possible cases and arguing that they are at least coherent, even if they do not actually obtain (for some examples, see Fine, 1995). Consider mathematical structuralism, for example as articulated by Stewart Shapiro: "the essence of a natural number is the relations it has with other natural numbers" (2000, 5). It is true that structuralists tend to explain this in terms of each number asymmetrically depending on the mathematical

[29] The literature often contains references to entities being 'wholly distinct' (e.g., Armstrong, 1997, 18). If the qualifier 'wholly' is not redundant here, it is reasonable to read it as indicating a notion of distinctness which is not simply non-identity (Wilson, 2010, 603–604).

[30] A similar proposal is offered by Karen Bennett. She notes that entities which are built are modally constrained by those from which they are built (where 'built' refers to any of range of what Bennett terms 'building relations', which include grounding). However, "this constraint on recombinability simply does not apply to entities that are not built, and no other constraint suggests itself. The claim is therefore compelling; there is no reason to deny that fundamental (independent) entities are freely recombinable" (Bennett, 2017, 190).

[31] A similar point applies to Bennett. Essential connections are not building relations as Bennett characterizes the latter; they are symmetrical, whereas building relations are antisymmetrical. So it may be that unbuilt entities are not freely recombinable, because they are essentially connected with each other.

structure to which it belongs: "The number 2 is no more and no less than the second position in the natural number structure; and 6 is the sixth position" (op. cit., 278). Therefore, this view might seem to be one on which the natural numbers are each grounded in the overall structure to which they belong. But an alternative interpretation is to say that each number essentially depends on all the others, and the structure as a whole depends on the numbers taken together rather than the numbers being grounded in the structure. This point can be developed by drawing on Øystein Linnebo's distinction between objects depending on the other objects in a domain (ODO) and objects depending on the structure to which they belong (ODS) (2008, 67–68). Linnebo mentions that ODS is possible without ODO (ibid., 69). What we are suggesting in this example, and more generally, is that ODO is possible without ODS—that is, the objects in a given domain may mutually depend on each other without (essentially) depending on the structure of that domain.

We also question Hume's Inference, the suggestion that modally connected entities cannot be wholly distinct. Given Hume's Inference, if electron x and electron y are entangled they cannot be wholly distinct: they must be connected by grounding, or perhaps be essentially connected, or meet some of whichever other conditions one thinks are sufficient for entities to not be wholly distinct. But why should this be accepted? First, it is hard to see how Hume's Inference can be accepted without clarifying the relevant notion of being wholly distinct; and as we have seen, the definition offered by Ismael and Schaffer is open to question. Second, in Sect. 10.3 we offered a different metaphysical account of modal connections, one which does not seem to fit Hume's Inference: x is essentially disposed to become modally connected (in certain circumstances) with other entities; when x is in this circumstance with y, x and y will become modally connected with each other. But on our account, there is no reason to think that x and y couldn't be wholly distinct (on a given understanding of such distinctness). This account is at least prima facie coherent; it appeals to metaphysical notions such as essence and dispositions which, though controversial, are well-known and widely used in other contexts. If this account is at least a coherent possibility, then one cannot simply appeal to Hume's Inference to rule it out; one would also have to provide independent support for Hume's Inference. Ismael and Schaffer do not provide such support (nor does Schaffer in his other work). This is not to suggest that no such support can be provided, only that without it, Hume's Inference cannot be used to undermine the account we have outlined.

10.6 Conclusion

Ismael and Schaffer argue that the best explanation for why entangled particles are modally connected is that they share a common ground. We have argued that there is another explanation which they do not consider: that modal connections can be explained by appeal to the essences of the entangled particles. We have developed this explanation by appealing to essential dispositions (though in principle this kind

of explanation could be developed in different ways), and we have argued that our account compares favourably with, or at least does as well as, a common ground account on a number of criteria.

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