Identity in Physics

Statistics and the (Non-)Individuality of Quantum Particles

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Abstract

This paper discusses the identity and individuality (or lack thereof) of quantum mechanical particles. It first reconstructs, on the basis of the extant literature, a general argument in favour of the conclusion that such particles are not individual objects. Then, it critically assesses each one of the argument's premises. In particular, the focus is set on the debate about quantum statistics and non-qualitatively-analysable identities. The upshot is that, in fact, there is no compelling reason for believing that quantum particles are not individual objects.

Introduction: the general argument against the individuality of quantum particles

The issue whether the most fundamental entities described by non-relativistic quantum mechanics are individual objects is of interest for both philosophers of physics and metaphysicians. Indeed, not surprisingly, it has received a great deal of attention lately. It is useful to frame the corresponding discussion in the context of a general argument that summarises all the relevant theses:

1. The Identity of the Indiscernibles (PII) – as shown, for instance, by French and Redhead [1988] - fails in the domain described by non-relativistic quantum mechanics (QM);
2. The only possible sources of individuality are PII and the Scholastic *primitive thisness* (PT) - a non-analysable, *sui generis* non-empirical posit[1] corresponding to 'brute' self-identity and numerical distinctness;
3. PTs are metaphysically suspicious, or at least they should be taken to be by those who look at science when formulating their metaphysical claims (so endorsing some form of *naturalism* about metaphysics). If PTs are primitive, non-empirical properties, how can we gain access to them empirically? If we cannot, on which basis do we postulate them?;
4. PTs entail *haecceitism*, that is, they entail non-qualitative differences between worlds (i.e., systems of objects) such that these worlds only differ *de re* with respect to what they say about certain individuals, without differing with respect to their qualitative features;
5. QM contradicts haecceitism for, unlike in classical statistics, in quantum statistics we are told that permuting two identical particles does not give rise to a new statistically relevant state, and the probabilities are distributed accordingly. But if haecceitism were true, this would not be the case. More briefly, permutation invariance entails anti-haecceitism and, therefore, QM contradicts the claim that objects are individuals because they possess PTs (from 3) and 4));

[1] Meaning, basically, that it is a *purely metaphysical* posit that is not directly causally efficacious and, therefore, cannot be known in itself. Whether this also means that it should be left out of the domain of what we conjecture to be 'real' on the basis of our best science is, as we will see, more controversial than is normally believed.

6. *Since (given 1), 2) and 5)) no source of individuality is available for quantum particles, we must conclude that QM tells us that particles are not individual objects.*

This paper will focus on quantum statistics, that is, on premises 4) and 5). Consequently, the discussion will mostly be devoted to issues surrounding permutation invariance, haecceitism and PTs. Its aim will be to clarify certain confusions, propose an individual-based account of quantum statistics alternative to those currently on offer and, more generally, outline and defend a plausible conception of primitive intrinsic identity and individuality. Before doing all this, however, let's look at the other three premises, that is, 1)–3) above.

Indiscernibles and primitive thisnesses

Against premise 1) above, Muller, Saunders and Seevinck (Saunders [2006a], Muller and Saunders [2008], Muller and Seevinck [2009]) have recently provided arguments to the effect that quantum particles are at least *weakly discernible*. That is, they can in some cases have all the same monadic and relational properties, but are *always* discerned by symmetric and irreflexive relations holding among them. In particular, spin correlations and more general commutator relations (involving, e.g., position and momentum) discern both fermions and bosons in all types of quantum mechanical systems and in Hilbert spaces of any number of dimensions. These arguments rely on plausible but not absolutely uncontroversial assumptions concerning the ontological status of relations, and whether the relations constructed in the presented proofs truly are metaphysically genuine properties.[2] At any rate, without undertaking a detailed examination of

[2] Muller, Saunders and Seevinck start from single-particle operators whose physical significance is quite uncontroversial, and go on to *construct* relations out of (some of) the corresponding projectors and their possible values.

Muller, Saunders and Seevinck's claims, it is sufficient here to state that *if* we accept their basic assumptions, it looks like premise 1) is false and some form of PII actually holds in QM. (Notice in this connection that Muller, Saunders and Seevinck are right in rejecting the charge of circularity that has been levelled against them: for, they assume the countability of particles at the *formal* level and then inquire into their *physical* discernibility; hence, it is an (alleged) genuine empirical 'discovery' that (allegedly) justifies their taking what is described by quantum theory to correspond to genuine objects).

It is important to point out, however, that Muller, Saunders and Seevinck claim that weakly discernible objects are not individuals but 'relationals', which entails that PII still doesn't ground individuality in the quantum case. However, the distinction between individuals and relationals only follows from a *definition* of individuality as absolute discernibility which it is not necessary to accept. In fact, on what one may take as a more appropriate 'philosophically neutral' construal of the notion, individuality consists of the possession of well-defined identity conditions (self-identity and numerical distinctness from other things) and, consequently, 'separate existence' (perhaps, for extended periods of time, i.e., in the diachronic as well as in the synchronic sense). Clearly, this means that individuality need not coincide with the strongest (or, for that matter, with any) form of discernibility; in fact, on this view one may regard all objects as individuals. Be this as it may, it seems fair to claim that, at the very least, there are grounds for questioning premise 1). On a related note, Ladyman and Bigaj [2010] cast doubt on Muller, Saunders and Seevinck's claim that weak discernibility vindicates PII. They argue that such form of discernibility doesn't correspond to the possibility of *actually* telling particles apart from each other through physical means, and consequently betrays the correct empiricist rendering of the Leibniz-Quine take on individuality. Independently of whether or not this is what led Muller, Saunders and Seevinck to (or, at any rate, justifies their) the introduction of the concept of a relational, if Ladyman and Bigaj's complaint is correct then premise 1) is in fact true. For present purposes, suffice it to emphasise again that, *under* *certain assumptions*[3], PII can be said to hold in QM, and premise 1) accordingly rejected.

Moving now on to premise 2), surely individuality can be extrinsic and qualitative (as the supporters of PII have it) or intrinsic and non-qualitative (as contended by the Scholastic tradition that postulates PTs). But – if only by counting the combinations! – it can be easily seen that a third option is in fact available and, in fact, explicitly defended by some authors. Ladyman [2007], for instance, takes identity to be extrinsic (as with PII) but non-qualitative (as with PTs). He argues that this is the view that best accounts for current science: it certainly makes sense of the branch of mathematics known as graph theory, where systems exist that are constituted by several objects which are not even weakly discernible; and it easily accommodates physical theories such as General Relativity and QM. So much so, Ladyman claims, that it is legitimate to formulate so-called 'contextualism' about identity as a thesis that applies generally.[4]

Besides allowing for the rejection of 2), this is also relevant with respect to 3). For, contextualism offers an analysis of facts of identity and difference which is not carried out in terms of qualities and yet, this notwithstanding, is considered to be supported by science, rather than in conflict with it. If this is true, then even in the context of a naturalist conception of metaphysics – aiming, as we have mentioned in the introduction, to ground metaphysical claims on empirical data and well-established scientific theories – non-qualitatively-analysable identities and individualities are acceptable. In other words, the internal consistency and scientific credibility of contextualism about identity allows one to depart from the Leibnizian-Quinean

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[3] That is, if one endorses the 'neutral' definition of individuality above, and rejects Ladyman and Bigaj's request that metaphysical discernibility correspond to the availability of physical procedures to actually distinguish.

[4] The contextualist take on identity supported by Ladyman was endorsed earlier by Stachel (see, for instance, Stachel [2004]), who first developed it in the context of a discussion of General Relativity and the ontology of space-time. Like Ladyman, Stachel moved in his work from initial 'local' claims and results to the defence of contextualism as a thesis of 'global' validity.

tradition of grounding individuality in qualitative uniqueness, without *ipso facto* entering the dangerous domain of non-scientifically-informed metaphysics.[5] But this means that the protest - expressed in premise 3) - against PTs as metaphysically suspicious 'factors' can be resisted (especially so if a valid alternative to PT is identified – more on this in a moment). For, the only difference between contextual and intrinsic primitive identity concerns the *n*-adicity of the relevant properties (non-qualitative identity- an difference-making relations between things in one case, monadic identity properties of things in the other); and this, of course, can hardly ground a general differentiation between 'good' and 'bad' metaphysical posits. More specifically, either

1) PT is a mysterious, inaccessible full-blown metaphysical property because it is non-qualitative, but then the relations posited by the contextualist also are; or
2) The contextualist claims that his/her talk of identity-relations must not be intended as ontologically 'thick' (that is, about full-blown metaphysical entities) but rather 'thin' (that is, not entailing ontological commitment), but then PTs can be conceived of as equally thin.

And since it is clear that the naturalist who endorses contextualism about identity will opt for a thin conception of the relevant elements (i.e., for option 2) above), it follows that *both* the relations considered fundamental by the contextualist and PTs can and should be regarded as only expressing the fact that things are self-identical and numerically distinct from everything else, with *no ontological addition* to what we regard as 'proper' things and properties.[6] This immediately restores the legitimacy of PTs

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[5] Clearly, this is relevant even beyond the context of the discussion of the ontological status of quantum particles, as it is connected to important general questions concerning the methodology one should implement when exploring issues at the boundary between empirical science and metaphysics.

[6] Recall, in this connection, that in their proofs Muller, Saunders and Seevinck need to *assume* the bare numerical difference grounding the countability of quantum particles. Although, as argued earlier, it is perfectly legitimate to do so, one may instead take countability to have a direct ontological import, that is, to justify

even within a naturalist setting, so leading to the rejection of premise 3) above.

One may complain that it is part of the *definition* of PT that it is *not* ontologically thin, as it is explicitly introduced as an additional metaphysical factor over and above objects and their properties. This reaction appears at least partly justified by the use of the notion in the literature, but doesn't require anything more than a conceptual-terminological qualification. Indeed, it appears useful to restrict the label 'primitive thisness' or 'haecceity' to primitive intrinsic identity intended as a 'thick' metaphysical property, truly additional to other properties of things – something like the individuating factors posited by Duns Scotus as what makes a collection of properties a genuine individual existent[7]; and, at the same time, also conceive of a non-inflationary, thin form of primitive intrinsic identity that simply corresponds to fundamental facts of self-identity and numerical uniqueness. From now on, talk of PTs will thus be set aside, and primitive intrinsic identity intended exclusively in the weaker sense just illustrated.[8]

If the foregoing is correct, it follows that the whole range of options with respect to individuality is in fact available for quantum particles, at least as things stand so far: for, not only Leibniz/Quine individuality as rooted in discernibility but also primitive identity and individuality – *both* contextual and intrinsic – are open possibilities, even for naturalists about metaphysics. In particular, the question whether primitive intrinsic individuality is possible for quantum particles by no means receives an obvious answer.

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talk of individuality even independently of considerations concerning (in-)discernibility.

[7] Scotus certainly intended *haecceitates* as full-blown metaphysical components of individuals.

[8] Incidentally, the metaphysically deflationary reading of primitive intrinsic identity and individuality also goes back to the Scholastic tradition, although to the ramification of it shaped by Ockham's nominalism rather than by Scotus' realism. Ockham surely did *not* intend haecceitates as ontological additions to objects and properties.

Consequently, those who like to think that the ontological status of an entity as belonging to this or that fundamental ontological category (in particular, to that of individuals) is entirely determined by factors *internal* to it still have some hope that their view can be defended in spite of the evidence coming from quantum mechanics.

In view of this, obviously enough, the careful examination of quantum statistics and its metaphysical consequences (premises 4)-5)) becomes all the more important and interesting.

Quantum statistics, primitive identity and haecceitism

The problem with quantum statistics, as is well-known, is that it is radically different from classical statistics, which deals with what one would take as paradigmatic individual objects. Considering two systems and two available states, for example, classically one gets four possible combinations (consider two fair coins). In the quantum case, instead, these are only three (consider two (qualitatively) identical bosons in the same system) or one (for identical fermions). In particular, in quantum mechanics only (anti-)symmetric states are possible – this is the well-known 'Permutation Symmetry' typical of the quantum domain.

The traditional explanation for this, which some authors (for example, French and Krause [2006]) call the 'Received View', is that particles are not individual objects, and this is why we shouldn't expect physical states to be sensitive to *which* one of them has which property: if an object is not an individual, it doesn't have a well-defined identity, distinct from that of other objects; consequently, there are no permutations to be made in the first place, let alone distinct states differing only with respect to permutations of identical items.

If one doesn't like this, it is an option to simply refrain from drawing metaphysical conclusions from the physics – but of course this is not what we want to do here. Making identity contextual *à la* Ladyman is also a solution, for if the identity of a thing is extrinsically determined by relations, then swapping things by keeping the relations fixed doesn't give rise to new arrangements of things, genuinely distinct from the original ones (this is in fact one of Ladyman's argument for contextualism). The most interesting question is, however, whether an intrinsic notion of primitive identity can be preserved in spite of the evidence coming from quantum statistics.

What immediately pulls towards a negative answer to this question is that even though, as we have seen, the postulation of primitive intrinsic identities doesn't force one to posit metaphysically suspicious Scotian PTs, it seems to lead anyway into a problem having to do with *modality* (see premise 4) of the main argument). For, regardless of what specific conception of primitive intrinsic identity one employs, one may think that the following holds: if things are primitively and intrinsically individuated, it immediately becomes possible for inhabitants of different possible worlds to be the same object, independently of what qualitative claims are true of tem in the respective worlds. Substituting worlds with statistically possible arrangements, one immediately sees that this is exactly what permutation invariance rules out in the quantum case (which is the reason why Ladyman and other contextualists contend that even if PII doesn't hold identity and individuality *must* in any case be extrinsically determined, in the quantum domain as in others).

However, this is too quick: although primitive intrinsic identities as 'bare identities' are *necessary* for haecceitism (unless one regards trans-world identity as primitive, which is an option but not a very natural one, especially if realism about possible worlds is not taken seriously), primitive intrinsic identities are not *sufficient* for actual haecceitistic differences.

First of all, i) *primitive intrinsic identities need not entail haecceitism*. As a matter of fact, intra-world identities and trans-world identities are at least partially independent, in the sense that there is room for different combinations of views about each of them; and, importantly, some of these combinations admit of bare identities *without* also entailing haecceitism. A typical example is the possibility of adopting counterpart theory with respect to modality, so denying that the *same* individuals can be arranged in a different but qualitatively identical way by rejecting the idea that the same individual can exist in more than one world - that is, by making identities 'world-bound' (incidentally, this option has been explored in the philosophy of physics in the past - specifically, in the debate about space-time point substantivalism and the hole argument by Butterfield [1989] and Brighouse [1994]).

Moreover, ii) *even if haecceitism holds, primitive intrinsic identities need not determine actual (i.e., physically relevant) haecceitistic differences*. Haecceitism is the thesis that there *may be* haecceitistic differences between worlds, not that there *are* and, with respect to the physics of the actual world, this can be translated into the claim that there may be reasons, *other than the lack of primitive intrinsic identity*, for which such differences are not manifested. Indeed, the enemy of primitive intrinsic identity and individuality typically *assumes the classical world as a paradigm*, and consequently deems the peculiarities of quantum statistics sufficient for showing that quantum particles do not possess primitive intrinsic individuality. However, this is a mistake (one that, one may add bluntly, is distinctive of the entire Received View on the ontological status of quantum particles). The supporter of primitive intrinsic identity and individuality can, and indeed should, *explain why* the haecceitistic differences made possible by the fact that individuals have primitive intrinsic identities are not manifested in a certain sub-domain of the actual world *by pointing to non-classical features, other than non-individuality, of that domain*.

In particular, this can be done in the context of QM. In fact, a number of options have been already discussed in the literature with a view to accounting for permutation invariance without involving the identity-conditions and ontological nature of quantum particles. It is true, on the other hand, that as things stand one may remain unsatisfied. The use of counterpart theory appears unavailable in QM, for unlike in the case of space-time points and models, there seems to be no way of defining the counterpart relation so that it performs the required work (see Teller [2001]).[9] And other options have been put forward which are also not ex-

[9] Teller's claims to this effect are not completely uncontroversial, but it is at least fair to claim that skepticism about counterpart theory may lead one to consider this option unappealing anyway.

empt from problems: revising the equiprobability of the possible states (Belousek [2000]), restricting the accessible states (French and Redhead [1988]), attributing indistinguishability to all particles, classical and quantum, and blaming the difference between classical and quantum statistics on the difference in probability measures (Saunders [2006b]). Without getting into a detailed discussion of each of these proposals, suffice it to say that either they put into question elements that one may prefer leaving untouched; or they introduce assumptions that are not well-argued-for.

An unexplored alternative, however, exists that provides a satisfactory explanation while also minimising the amount of revision required with respect to our entrenched beliefs about things. Or so it will be claimed in the rest of this paper.

An account of quantum statistics focusing on properties rather than property-bearers

The claim in what follows will be that a key, though dispensable, assumption is normally made concerning the continuity between classical mechanics and QM with respect to their 'property-structure', that is, the way in which properties are possessed by particles; that modifying this assumption is plausible, minimally revisionary, and explanatorily efficacious with respect to the problem at hand; and, crucially, that doing this preserves (or allows one to postulate) particle individuality, *in whatever form,* without even requiring one to venture into the questions whether the relevant domain is haecceitistic or not and, if it is, in what sense.

The assumption being referred to is that *all state-dependent (i.e., statistically relevant) properties are possessed by individual particles as their monadic properties* (A). (A) clearly holds in the classical domain, where it provides a straightforward explanation for why we expect, say, four possibilities in cases like two fair coins. However, that this assumption holds is obviously not a metaphysical necessity, and a simple look at entangled states shows that, in fact, it doesn't hold in QM in at least some cases. Considering, for example, the singlet spin state, it is universally agreed that particles in that state do not possess any well-defined monadic state-independent spin property, and yet there is something meaningful that can be said about the total system, and therefore taken to be a genuine property: e.g., that there is a definite correlation between the spin values of the separate particles.[10] More generally, in the classical domain Humean supervenience - the doctrine that the whole of reality can be reduced to local matters of fact about objects exemplifying (local, monadic) properties plus spatio-temporal relations - holds, but (as is widely agreed) this is not the case in the quantum domain.

But if this is true, why exactly should one accept the failure of Humean supervenience in cases such as entangled fermions, but stick to the classical picture when it comes to the other cases? I want to suggest that there is no truly compelling reason for doing so, and that it is instead sensible to think that what is generally agreed to hold for certain quantum systems holds for others too. In fact, I will contend that there are reasons for thinking that *all* state-dependent properties of quantum particles in many-particle systems (entangled *and* non-entangled) are properties expressing correlations and nothing more than that.[11]

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[10] These correlations can be taken as categorical irreducible relations, as suggested for instance by Muller, Saunders and Seevinck, but also as (monadic or relational) dispositions for measurement outcomes. Which option is to be preferred doesn't matter here.

[11] It may be objected that one should presuppose supervenience whenever possible, and so non-factorisable entangled states should be deemed 'metaphysically special'. However, 1) I think the explanatory efficacy of a presupposition to the effect that (A) fails in general, and in particular the fact that such a presupposition allows one to stick to commonsense at a more important level (that of the ontological status of particles and larger physical systems) suffices for resisting the objection; moreover, 2) it is possible to implement criteria for evaluating the non-reducibility of global to local properties that make quantum non-supervenience independent of, and non-reducible to, entanglement and non-factorisability: Seevinck (2004), for instance, proposes one such criterion, based on the local resources available to agents (so suggesting a shift from an ontological to an epistemological justification for claims of (non-)supervenience and holism).

Let us call *inherent-holistic* those properties of wholes (composed of two or more parts) that

1) Are not reducible to properties of the parts of those wholes;
2) Convey information about such parts without also conveying specific information about any specific part.

The conjecture being put forward amounts to the claim that *all quantum state-dependent properties are inherent-holistic properties*.[12] The explanatory efficacy of this conjecture with respect to quantum statistics is easily appreciated by noticing that 1) and 2) above entail that inherent-holistic properties only express *correlations* that are not reducible to monadic properties; and that, consequently, quantum statistics only deals (and can only deal) with irreducible correlations of this sort. Indeed, the conjecture that quantum statistics only describes (non-reducible) correlations straightforwardly explains permutation symmetry without questioning the status of identities, modality, probabilities, classical distinguishability etc.: for, permuting the specific entities involved in a (non-reducible) correlation doesn't affect the correlation itself, but it is being assumed that the latter is *all* that is relevant.

In particular, as promised, the picture just suggested avoids the question of whether haecceitism holds in the quantum domain. For, clearly, if it is correct, there are no manifest haecceitistic differences in the quantum case, but these are explained on the basis of a conjecture involving the relevant *properties*, not identities; the possibility can consequently be left open that, *were* particles to possess monadic intrinsic state-dependent properties, they *would* indeed exhibit statistically relevant haecceitistic behaviour.

Notice that on this construal one also straightforwardly accounts for the impossibility of non-symmetric states, another puzzle raised by QM: these states require separate, well-defined (and distinct) states and properties for

[12] This might be restricted to systems of identical particles, but whether or not one does so is not crucial here.

the separate components of the total system, which is exactly what the present proposal rules out.

Before closing, a few additional remarks. The suggested view of quantum systems basically consists of an extension of the sort of holism outlined by Teller [1986], [1989] and Healey [1991] for entangled states to non-entangled states. But it doesn't need to share the specific details of these views: most notably, with respect to Teller's proposal, it is not necessary here to assume that the inherent holistic properties are genuine, fundamental relations. The proposal also requires something. First, it demands that clear criteria be given for identifying genuine multi-particle wholes (we certainly don't want to attribute inherent, holistic properties to any set of several particles described as a whole via the formalism); this is likely to be achieved by emphasising the role played by actual causal interaction between particles, but there's no space to say more about this here. Secondly, we must also require that in the relevant systems only *total-system symmetric operators* correspond to genuine observables (not single-particle operators, not even when an eigenvalue for the corresponding (alleged) observable is possessed with probability 1). For, otherwise the claim about the inherent-holistic nature of quantum state-dependent properties - which certainly plays a crucial role in the proposal - could not have the needed generality. This entails, if anything, a slight modification to the eigenstate-eigenvalue link, but the latter is certainly not an indispensable part of the theory, and just represents a possible interpretative rule.

More details can be found elsewhere (Morganti [2009]). Here, the main point to be made is that, if the foregoing is correct, there is no reason for thinking that 5) is actually true; hence, even if one takes 4) to be true, the claim that QM contradicts the view that individuality is determined by the possession of primitive intrinsic identities doesn't follow. As a consequence, primitive intrinsic individuality becomes (remains?) a viable option for quantum particles - even for naturalists about metaphysics!

Conclusions

The argument - summarised in 1)-6) above - in favour of the conclusion that quantum particles are not individual objects can legitimately be said to fail entirely. The only true part in it is 4), which is, however, a general metaphysical thesis that, by itself, cannot have any bearing with respect to the ontological import of quantum mechanics. Hence, it is certainly *possible* to reject 6) as the conclusion of a valid but unsound argument, and believe that quantum particles are, after all, individuals. In particular, primitive intrinsic identity and individuality need not, claims to the contrary notwithstanding, be looked at with suspicion by the scientifically-minded philosopher.

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