On individuating quantum particles

Quantum mechanics forces us to revise some of the most fundamental concepts with which we describe reality. Among the 'metaphysical' concepts subject to quantum revision are those of object, identity, individuality and discernibility. The quantum theory of many particles introduces the Indistinguishability Postulate regarding the states of systems of same-type particles (groups of electrons, protons, neutrinos etc.), which prescribes that permutations of such particles should not have any observable effects. This leads to a superselection rule limiting the available states of a particular group of same-type particles to permutation-invariant subspaces, of which the symmetric and antisymmetric spaces are known to correspond to bosons and fermions, respectively. This, in turn, has the consequence that particles of the same type cannot be discerned by their state-dependent properties or by their relations with other particles (this is known as the breakdown of *absolute discernibility*). The received view is that particles of the same type violate the Principle of the Identity of Indiscernibles (PII), and that their status of individuals becomes problematic as a direct result of this violation. An attempt to save the individuality of quantum particles by resorting to so-called *weak discernibility* (discernibility with the help of symmetric and irreflexive relations) has met with mixed reactions. It is thus common to interpret multipartite systems of 'identical' particles as aggregates rather than collections of individuals.

However, the connection between the validity of PII and the individuality of objects is not as close as one might think. An individual is an object whose identity can be 'traced' over time, as well as when shifting from the actual to possible scenarios. In particular, switching two individuals should create a counterfactual situation distinct from the original one. But since particles of the same type share all their state-independent properties (rest mass, charge, total spin etc.), switching them has no empirically verifiable effect. Even if two objects can be discerned by their properties at a given instantaneous moment, this does not ensure that they are individuals in the above sense, since their discerning properties may be merely contingent and not essential. To be an individual, an object should possess its unique essence that enables us to identify it over time and in alternative situations.

The received view can be questioned on a more fundamental level too. It is gradually becoming more acceptable that the notion of absolute discernibility may be applicable to particles of the same type after all, in spite of the necessary permutation-invariance of their states. First off, there are some logical results which prove that the symmetricity (i.e. permutation invariance) of a language does not exclude the possibility of expressing facts about the absolute discernment of objects referred to in this language. This follows from a theorem, due to Simon Saunders, which states that for any sentence true in a finite domain there is an equivalent sentence using only a totally symmetric predicate. In the quantum-mechanical formalism of permutation-invariant systems, sentences about absolute discernibility can be recovered using symmetric projection operators of the form $P_u \otimes P_v + P_v \otimes P_u$, where $P_u = |u\rangle\langle u|$, $P_v = |v\rangle\langle v|$, and $|u\rangle$, $|v\rangle$ are orthogonal vectors in a one-particle Hilbert space. It may be argued that the projector $P_u \otimes P_v + P_v \otimes P_u$ represents the disjunctive 'discerning' property "One particle is in state $|u\rangle$ while the other is in state $|v\rangle$". And it can be easily shown that there are symmetric and antisymmetric states which are eigenstates of the above projector, which strongly suggests that particles in these states are indeed discerned by their properties. Moreover, it can be formally proven that for all fermionic states ψ_A there is a one-particle projector P (not necessarily one-dimensional) such that ψ_A is an eigenvector for $P \otimes (I - P) + (I - P) \otimes P$, which shows that fermions are *always* discernible by some properties.

The new approach to the issue of quantum (in-)discernibility requires some major and rather unorthodox alterations of the way we interpret the quantum-mechanical formalism of many-particle systems. In particular, we have to abandon the doctrine known as "factorism", i.e. the assumption that factor Hilbert spaces in the tensor product of many spaces represent states of separate components of the system. Instead, we use symmetric projectors of the above form to make appropriate identifications of the components. Another problem that has to be addressed is the existence of a multitude of alternative individualizations for fermionic composite systems, which prompts some form of ontological relativism or perspectivalism. Finally, a closer look at measurements performed on systems of 'indistinguishable' particles has to be taken, with an eye on the role of the spatial degrees of freedom in selecting individual particles. Once this is done, the ontological picture that emerges from this unorthodox approach will be as follows. Quantum particles of the same type can be synchronically individuated by their momentary properties (this can be done for all fermionic states and a significant number of bosonic states), which saves the letter of PII. However, this method of individuation is seriously limited in three ways. It does not enable us to make diachronic identifications, especially with interacting particles. Similarly, it does not extend to identifications in possible worlds. And it often requires a relativization to some preselected orthogonal basis. In conclusion, while quantum objects can be absolutely discerned, they are definitely not individuals in the ordinary sense of the word.

Selected bibliography

Bigaj, T., "Dissecting weak discernibility of quanta", *Studies in History and Philosophy of Modern Physics*, (2015) 50, 43-53.

Bigaj, T., "On some troubles with the metaphysics of fermionic compositions", *Foundations of Physics*, (2016) 46(9), 1168-1184.

Caulton, A., "Qualitative individuation in permutation-invariant quantum mechanics", (2014) arXive: 1409.0247v1 [quant-ph].

French, S., and Krause, D. *Identity and Physics: A Historical, Philosophical and Formal Analysis.* (2006) Oxford: Clarendon Press.

Saunders, S., "On the Explanation of Quantum Statistics", *Studies in the History and Philosophy of Modern Physics* 2006 *37*: 192–211.