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Vague Identity and Quantum Indeterminacy

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A curious omission in the burgeoning philosophical literature on vague objects and vague identity has been the absence of much serious discussion of the bearing of quantum indeterminacy upon this issue. Standard quantum-theoretical treatments of certain types of particle-interaction suggest that we *can* intelligibly countenance ontically indeterminate identity statements, contrary to the widespread philosophical opinion that vagueness must reside in our linguistic representations rather than in the world.

Before commenting on the best-known argument for this philosophical opinion, let me illustrate the sort of quantum-theoretical situation I have in mind. Suppose (to keep matters simple) that in an ionization chamber a free electron *a* is captured by a certain atom to form a negative ion which, a short time later, reverts to a neutral state by releasing an electron *b*. As I understand it, according to currently accepted quantum-mechanical principles there may simply be no objective fact of the matter as to whether or not *a* is identical with *b*. It should be emphasized that what is being proposed here is *not* merely that we may well have no way of telling whether or not *a* and *b* are identical, which would imply only an epistemic indeterminacy. It is well known that the sort of indeterminacy presupposed by orthodox interpretations of quantum theory is more than merely epistemic – it is *ontic*. The key feature of the example is that in such an interaction electron *a* and other electrons in the outer shell of the relevant atom enter an 'entangled' or 'superposed' state in which the *number* of electrons present is determinate but the identity of any one of them with *a* is not, thus rendering likewise indeterminate the identity of *a* with the released electron *b*.

I should remark that it would be wrong to assume that quantum theory poses problems for the synchronic individuation and diachronic identity of

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electrons *quite generally*, and hence casts doubt upon the legitimacy of our description of the preceding example in terms of an identifiable electron *a* existing prior to the interaction and an identifiable electron *b* existing subsequent to it.[1] Here it is important to note that electrons are *fermions* (as opposed to *bosons*, a class of particles exemplified by photons) and consequently do appear to have determinate identity attributable to them both *at* a time and, I believe, even *over* time when they are not interacting with other particles in such a fashion that they enter into an 'entangled' or 'superposed' state. What distinguishes fermions from bosons is that only the former are governed by the Pauli Exclusion Principle (the principle that no two fermions of the same kind in any system can be in the same quantum state). This is the principle which ensures, for instance, that a lithium atom must have its third electron in a second shell at a different energy-level from the innermost two, which differ only in their direction of spin.[2]

At this point let us turn to a well-known philosophical argument against indeterminate identity. In 'Can There Be Vague Objects?' ([1]), Gareth Evans famously argued that no identity sentence '$a = b$' (where 'a' and 'b' are singular terms) can be of indeterminate truth value. Since the issue is whether vagueness can reside in the world rather than merely in language, I take him to have meant by this that for any individuals *a* and *b* there cannot fail to be an objective fact of the matter as to whether or not they are identical. As we have just seen, the deliverances of modern quantum physics would appear to be at odds with this claim, so we need to look carefully at Evans's attempted proof of his claim.

Evans proposes that we 'allow for the expression of the idea of indeterminacy by the sentential operator "∇"'. Thus, on the supposition that '$a = b$' is of indeterminate truth value, we have, he says,

(1) $\nabla(a = b)$

Evans takes (1) to entail

[1] It is true that some philosophers of quantum physics would agree with Michael Redhead that quantum field theory is best understood purely in terms of 'quantized excitations of a field' (Redhead [5], p. 18), but even Redhead considers that it is perfectly *intelligible* to interpret quantum phenomena in the more familiar way, in terms of individual particles (see French and Redhead [2] and Redhead and Teller [6]). The intelligibility of such more familiar interpretations is all that currently concerns me, not the deeper question of whether particle or field interpretations are superior on grounds of parsimony and the like.

[2] For technical details and illuminating discussion, see van Fraassen [7], Ch. 11 and 12; van Fraassen's verdict on the question of whether elementary particles can be individuated in quantum-theoretical terms is that 'the answer is *yes* for fermions and *no* for bosons' ([7], p. 480). I am indebted to an unpublished paper by Peter Simons for alerting me to the importance of the fermion/boson distinction in the present context.

(2) $\hat{x}[\nabla(x = a)]b$

ascribing to b the property '$\hat{x}[\nabla(x = a)]$'. But supposedly we also have

(3) $\neg\nabla(a = a)$

and hence

(4) $\neg\hat{x}[\nabla(x = a)]a$

However, by Leibniz's law, we may derive from (2) and (4)

(5) $\neg(a = b)$

thus 'contradicting the assumption, with which we began, that the identity statement "$a = b$" is of indeterminate truth value'.

Evans's conclusion clearly conflicts with the quantum-theoretical verdict that, in our electron example, there may simply be no objective fact of the matter as to whether or not the released electron b is identical with the captured electron a. Now, of course, perhaps the accepted principles of quantum mechanics are wrong and in the future a superior theory of sub-atomic phenomena will show that there *must*, after all, be an objective fact of the matter as to whether or not our electrons a and b are identical. But it is surely clear that Evans's argument will contribute in no way to the founding of any such new theory. I make this point in order to emphasize that my proposed counterexample to Evans's claim does not really depend for its force upon the *correctness* of current quantum theory or of its standard interpretation: it is enough that *it makes sense* to suppose that there is no objective fact of the matter in the case envisaged, that is, it is enough that Evans's argument cannot impugn the *coherence* of currently accepted views.

Where, then, can Evans's argument have gone wrong? At least the following five possibilities (not all of them mutually exclusive) suggest themselves. (i) It is improper to express indeterminacy by a sentential operator like '∇', that is, it is wrong to treat the *lack* of any objective fact of the matter determining the truth or falsity of a sentence S_1 as itself being just a particular objective matter of fact capable of being reported by a true sentence S_2 obtainable from S_1 by a logical operation. (ii) It is mistaken to regard '$\hat{x}[\nabla(x = a)]$' as expressing a genuine *property* of any sort, that is, there can be no such thing as the 'property' an object has just in case there is no objective fact of the matter as to whether or not it is identical with the object a. (iii) It is incorrect to suppose that (1) entails (2) or that (3) entails (4). (Elsewhere, [3], I have queried the apparent analogue of the latter entailment in the standard 'proof' of the necessity of identity but, as will emerge below, I am strongly inclined to deny that the two 'proofs' are genuinely analogous, because I suspect that '∇' is a spurious operator in a way that '$\Box$' is not.) (iv) It is erroneous to assume that, whatever a may be, there must be an objective fact of the matter as to whether or not *a* is self-identical, that is, (3) cannot be assumed to be true. (I would be extremely loath to adopt this solution, because I consider the possession of determinate self-identity as the hallmark of entityhood, that is, as the minimum condition to be met for the classification of any item as an *object* of any sort. Note here that the *self-identity* of the electrons, including *a* and *b*, involved in the ionized state of the atom in our example is not in question: for it is not in question that there is a determinate and unchanging *number* of electrons involved, which presupposes that each one of them is indeed *one*, and hence *one and the same with itself*.) Finally, (v) Leibniz's law requires some kind of restriction. (Again, I regard this as a solution of the last resort.)

I confess to feeling a strong inclination towards adopting a combination of options (i) and (ii). For consider again the electron example. As we have seen, it seems perfectly coherent to suppose, with the quantum physicist, that there is no objective fact of the matter as to whether or not electron *a* is identical with electron *b*. According to Evans's argument this leads to a contradiction: if what the quantum physicist supposes were true, then there *would* after all be an objective fact distinguishing *b* from *a*, namely, the 'fact' that *b* possesses, whereas *a* does not, the 'property' which an object has just in case there is no objective fact of the matter as to whether or not it is identical with *a*. But this 'fact' and this 'property' seem to be, to say the very least, of highly dubious status and completely without empirical significance. We might agree that *a* does *not* possess any such property, but hold this on the grounds that there *is* no such property and so *a fortiori* no such property to be possessed by *b* either.

However, I realize that many logicians – albeit not many quantum physicists – will be less ready than I am to deny that '$\hat{x}[\nabla(x = a)]$' expresses a genuine property of any sort. For these logicians I have an alternative diagnosis of the error in Evans's proof, which is a variant of option (iii) above. Suppose we concede that electron *b does* possess the supposed property '$\hat{x}[\nabla(x = a)]$', as stated in line (2) of Evans's proof. Then observe that parity of reasoning must lead us to say, equally, that electron *a* possesses the symmetrical property '$\hat{x}[\nabla(x = b)]$'. However, given the quantum physicist's assumption that there is no objective fact of the matter as to whether or not electron *a* is identical with electron *b*, it surely follows that the property '$\hat{x}[\nabla(x = a)]$' possessed by electron *b* is not determinately distinct from the symmetrical property '$\hat{x}[\nabla(x = b)]$' possessed by electron *a*: for these 'two' properties 'differ' only by permutation of '*a*' and '*b*'. Consequently, the possession by *b* of the property '$\hat{x}[\nabla(x = a)]$' cannot serve to differentiate *b* determinately from *a*, since that property is not determinately distinct from a property which is possessed by *a*. The formal error in the proof thus lies in line (4), and more particularly in its derivation from line

(3). For if the property '$\hat{x}[\nabla(x = a)]$' is, for the reason just given, not determinately distinct from the property '$\hat{x}[\nabla(x = b)]$' which *is* possessed by *a*, it cannot be correct to *deny* that *a* has this property on purely logical grounds, that is, to derive this denial from the logical truth stated in line (3). (The technical implication of this diagnosis is that a formal restriction needs to be placed on the operation of property-abstraction, whereby from '$\neg\nabla(a = a)$' only '$\neg\hat{x}[\nabla(x = x)]a$' may be inferred.[3])

One final point: it may be worried that the quantum example of indeterminate identity that I have offered is not really an example of *vague* identity, of the sort that has preoccupied philosophers. The philosophers typically discuss putative examples involving macroscopic objects like mountains or seas, whose spatial boundaries seem to be indeterminate, thus inviting comparisons with vagueness in colour distinctions. (Evans himself, in [1], talks about 'the idea that the world might contain certain objects about which it is a *fact* that they have fuzzy boundaries'.) I reply, first, that identity *over* time is quite as much *identity* as is identity *at* a time and, secondly, that what is crucial to the issue is not the familiarity or otherwise of the kind of example under discussion but whether it really does constitute an intelligible example of indeterminate identity residing in the world rather than in our linguistic representations – and there seems little doubt that the present example does indeed constitute just this.[4]

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[3] Compare Lowe [3] and Lowe [4] for a defence of a similar restriction in the modal case.

[4] I am very grateful to Peter Smith for helping me to improve upon an earlier version of this paper.