# Vagueness and Quantum Indeterminacy

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# Readings

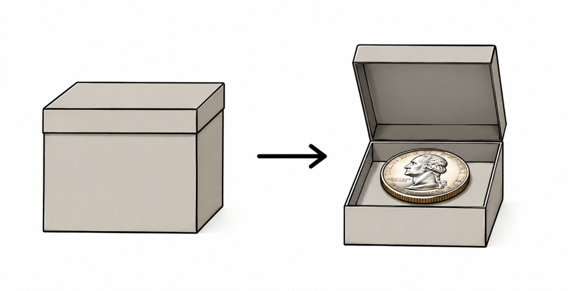

- Evans, G. (1978). “Can There Be Vague Objects?” *Analysis*, 38(4), 208.
- Lowe, E. J. (1994). “Vague Identity and Quantum Indeterminacy.” *Analysis*, 54(2), 110–114..
- French, S., Krause, D. (2003) “Quantum Vagueness.” *Erkenntnis* 59, 97–124 (2003).
- Williams, J. R. G. (2008). “Multiple Actualities and Ontically Vague Identity.” *The Philosophical Quarterly*, 58(230), 134–154.
- French, S., Bigaj T. (2024), “Identity and Individuality in Quantum Theory”, The Stanford Encyclopedia of Philosophy.

# Kinds of Indeterminacy

- **Semantic indeterminacy:** meaning or use does not settle whether an expression applies.
- **Epistemic indeterminacy:** there is a determinate fact, but we do not know it.
- **Metaphysical indeterminacy:** reality itself does not determine one unique precise state of affairs.
- **Quantum indeterminacy:** even when a system's quantum state is fully specified, the theory may assign probabilities to several measurement results.

# Coin: Epistemic Indeterminacy

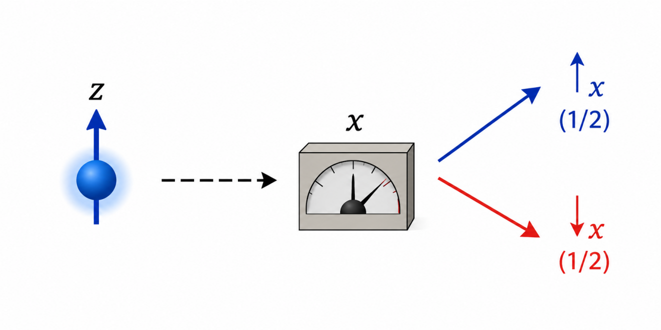
- A coin is placed in a closed box.
- It is already either heads or tails, although we do not know which.
- The indeterminacy is in our information, not in the coin.



# Measuring Electron Spin

- An electron has a quantum property called **spin**. It is not literally a spinning ball.
- A spin-measuring device must be oriented along a chosen direction.
- The device has two possible readings, conventionally called **up** and **down**.
- Prepare an electron guaranteed to give *up* when measured vertically (the $z$-direction).
- What happens if we instead measure it horizontally (the $x$-direction)?

# Spin Before Measurement



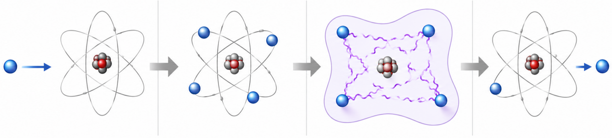

- A horizontal measurement gives *up* or *down*, each with probability $\frac{1}{2}$.
- Both predictions come from the same fully specified quantum state.
- On the textbook interpretation, the electron has no definite horizontal-spin value before measurement.

# From Properties to Identity

- So far, the question concerned a property: *Does electron* $a$ *have horizontal spin-up?*
- The identity question is different and metaphysically more demanding: is $a = b$?
- Could it be neither determinate that $a = b$ nor determinate that $a \neq b$?
- Indeterminacy about *which properties are possessed* does not automatically entail indeterminacy about *which object is which*.

# Lowe's Quantum Case

- A free electron, called $a$, is captured by an atom.
- It becomes part of a combined quantum state involving the atom's other electrons.
- The theory no longer provides a separately trackable history for each electron in that state.
- The atom later emits an electron, called $b$.
- Lowe (1994) asks whether it is indeterminate if $a$ and $b$ are the same electron.



Lowe 1994

# What the Quantum Formalism Tells Us

- Quantum mechanics describes identical electrons through a single joint state.
- Exchanging their mathematical labels makes no difference to any predicted observation.
- The labels therefore do not function like experimentally trackable names.
- The theory describes the combined system without identifying which later electron continues which earlier electron's history.
- But this leaves a philosophical question: is there no fact of identity, or does the formalism merely fail to represent or reveal it?

# Evans's Argument against Vague Identity

$\nabla\varphi := \neg\Delta\varphi \wedge \neg\Delta\neg\varphi$

Let $P_b$ be the putative property expressed by $\lambda x\, \nabla(x = b)$.

| | | |
|---|---|---|
| $(1)$ | $\nabla(a = b)$ | Assumption |
| $(2)$ | $P_b(a)$ | Property abstraction |
| $(3)$ | $\neg\nabla(b = b)$ | Determinate self-identity |
| $(4)$ | $\neg P_b(b)$ | Generalized property abstraction |
| $(5)$ | $a \neq b$ | From (2), (4), indiscernibility of identicals |

Evans 1978; Lewis 1988

# Which Premise Can Be Rejected?

- **Restrict property abstraction:** deny that every formula involving indeterminacy determines a discriminating property.
- **Allow referential indeterminacy:** deny that $b$ has one fixed referent across the relevant precise actualities.
- **Adopt quantum non-individuality:** deny that ordinary numerical identity applies to the quantum entities.
- **Reject the quantum example:** accept Evans's reasoning but deny that Lowe's case involves vague identity.

# Lowe: Rejecting Evans's Abstraction Step

- Lowe's preferred diagnosis is that $\nabla$ may not be a genuine sentential operator, or that $P_b$ fails to express a genuine property.
- His alternative, for those who allow such properties, rejects the move from (3) to (4).
- If $\nabla(a = b)$, then $P_b$ is not determinately distinct from the symmetrical property $P_a(x) := \nabla(x = a)$, which $b$ possesses.
- Determinate self-identity therefore does not, by itself, license the claim that $b$ lacks $P_b$.
- This comes at a cost: generalized property abstraction must be restricted in indeterminacy contexts.

Lowe 1994; French and Krause 2003

# Williams: A Supervaluation-Style Account

Let $w_1$ and $w_2$ be two precise actualities that equally represent one indeterminate reality:

| | $\mathrm{ref}(a)$ | $\mathrm{ref}(b)$ | identity statement |
|---|---|---|---|
| $w_1$ | $e_1$ | $e_1$ | $a = b$ |
| $w_2$ | $e_1$ | $e_2$ | $a \neq b$ |

- Identity remains classical within each actuality, but $a = b$ is true in $w_1$ and false in $w_2$.
- The term $b$ is referentially indeterminate because reality does not select one actuality, not because speakers were indecisive.
- In the Evans proof, (3) is true *de dicto*: whatever $b$ refers to is self-identical. But (4) does not follow, because $b$ has no single referent across the actualities.
- Williams defends ontically vague identity *statements*, not vague instances of the identity relation itself.

Williams 2008

# French and Krause: Why Quasi-Set Theory?

- Quantum mechanics can tell us how many electrons are present, but after capture and emission it does not assign each electron a traceable “biography.”
- French and Krause explore an optional **non-individualist** interpretation: perhaps “Which electron is it?” is not merely unanswerable, but inapplicable.
- Quasi-set theory represents such particles as $m$-atoms. For terms denoting $m$-atoms, $a = b$ and $a = a$ are not well-formed formulas.
- Evans’s argument therefore cannot begin: neither $\nabla(a = b)$ nor $\neg\nabla(b = b)$ is available.
- We can nevertheless collect and count these particles: $\mathrm{qc}(X) = n$ says that $X$ has $n$ members without requiring them to be individually identifiable.

Krause 1992, 1996; French and Krause 2003

# Appendix: Quasi-Set Theory

- Quasi-set theory extends Zermelo-Fraenkel set theory with urelements in order to represent collections of indistinguishable objects (think: many-sorted language).
- Two kinds of entities. The $M$-atoms behave classically. The $m$-atoms need not possess identity conditions.
- The primitive relation $x \equiv y$ expresses indistinguishability and is an equivalence relation.
- Extensional identity, written $x =_E y$, is defined for quasi-sets and $M$-atoms, but not for $m$-atoms. Thus $x \equiv y$ need not imply $x =_E y$.
- Membership $x \in X$ is retained, so quasi-sets may contain indistinguishable $m$-atoms even when their individual identities cannot be expressed.
- Each quasi-set $X$ has a quasi-cardinal $\mathrm{qc}(X)$, representing the number of its elements.
- The theory contains a classical subtheory isomorphic to ordinary set theory: when no $m$-atoms occur, quasi-sets behave like standard sets.

Krause 1992, 1996; French and Krause 2003