Identity-Based Bohmian Mechanics

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Outline

Conceptual Issues with QM

axioms of QM:

- observable.
- measurement.
- measurement postulate.
- measurement apparatus.
- collapse of the wave-function.

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$\rightarrow$ symptoms of a deep problem.

$\rightarrow$ lack of ontology.

Primitive Ontology

the primitive entities matter is made of.

the building blocks of matter.

candidates for primitive ontology:

1. particles,
2. matter density,
3. flashes,
4. strings.

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how does a physical theory reflect all this?

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distinguished by different positions alone.

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there is no paradox!

NB: in both cases particles always have precise position.

Confusion

Gibbs' Vorschlag, alle durch Vertauschen von Teilchen entstehenden Zustände bei der Berechnung [der Entropie] wegzulassen, war den Physikern zunächst nicht geheuer. Er fand aber Jahre später in der Quantentheorie eine einleuchtende Begründung. Demnach können identische Teilchen, die in allen ihren Eigenschaften übereinstimmen (Masse, Ladung, Drehimpuls, magnetisches Moment usw.), prinzipiell nicht voneinander unterschieden werden. Denn hätten sie ein Unterscheidungsmerkmal (eine Nummer, eine Farbe, einen festen Ort usw.), so wären sie nicht mehr identisch. Atome kann man aber nicht nummerieren, färben oder an bestimmte Plätze in einem Körper binden ohne ihre Eigenschaften oder ihre Struktur zu verändern. [7, p. 70]

Comments

position does not rule out indistinguishability.

identical particles are no novelty of QM.

Particles Are Not Individuals?

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Now in classical statistical mechanics [the two] arrangement[s] [. . .] would be counted as distinct and given equal weight in assigning probabilities. But in quantum statistics, whether bosonic or fermionic, the arrangements [. . .] are counted as one and the same arrangement for the purpose of assigning weights. This is taken to show that the two *arrangements* are not only indistinguishable but are actually identical. But ontologically speaking these two arrangements are *not* identical if the two quantum particles are individuals. Hence the quantum particles cannot be individuals. [4, p. 236]

Comments

the statement on classical mechanics is wrong.

often used to show an exceptional situation in QM.

what does it mean that particles are not individuals?

what is the alternative ontology?

individuated identical particles also in classical mechanics!

The Theory

configuration of particles: $Q(t) = (Q_1(t), \ldots, Q_N(t)) \in \mathbb{R}^{3N}$

guiding equation:

$$\frac{\mathrm{d}Q}{\mathrm{d}t} = \frac{j\,(Q(t))}{\rho\,(Q(t))},$$

with probability density

$$\rho = \psi^* \psi$$

and probability current $j = (\mathbf{j}_1, \ldots, \mathbf{j}_N)$,

$$\mathbf{j}_i = \frac{\hbar}{m_i} \operatorname{Im} \psi^* \nabla_i \psi.$$

Identical Particles

same situation as in classical mechanics.

identical = same mass.

particles individuated by position.

Identical Particles: The Natural Configuration Space

no label for identical particles.

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NB:

- complex topology of $^{N}\mathbb{R}^3$.
- derivation of boson/fermion alternative.

Sources: [3, Chap. 8] and [2, Sect. 8.5].

Identical Particles: Law of Motion

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$\rightarrow$ guiding equation permutation invariant for identical particles.

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different masses:

$\rightarrow$ guiding equation no longer permutation invariant.

$\rightarrow$ no law of motion on ${}^{N}\mathbb{R}^3$.

The Theory

all particles are identical.

→ dynamics on ${}^{N}\mathbb{R}^3$ for all particles.

→ symmetrized guiding equation:

$$\frac{\mathrm{d}Q_k}{\mathrm{d}t} = \frac{\sum_{\sigma \in S_N} \mathbf{j}_{\sigma(k)} \circ \sigma}{\sum_{\sigma \in S_N} \rho \circ \sigma}(Q(t)).$$

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only under certain circumstances "assignment" of mass.

Sources: [5] and [6].

Example: Two-Particle Universe

electron m_e, muon m_μ with

$$\Psi(q_1, q_2) = \phi(q_1)\chi(q_2).$$

standard guiding law:

$$\frac{\mathrm{d}Q_1}{\mathrm{d}t} = \frac{\hbar}{m_e} \operatorname{Im} \frac{\nabla\phi(Q_1)}{\phi(Q_1)},$$

$$\frac{\mathrm{d}Q_2}{\mathrm{d}t} = \frac{\hbar}{m_\mu} \operatorname{Im} \frac{\nabla\chi(Q_2)}{\chi(Q_2)}.$$

Example con't

symmetrized guiding law:

$$\frac{\mathrm{d}Q_1}{\mathrm{d}t} = \frac{\frac{\hbar}{m_e}\left|\chi(Q_2)\right|^2 \operatorname{Im}\left(\phi^*(Q_1)\nabla\phi(Q_1)\right) + \frac{\hbar}{m_\mu}\left|\phi(Q_2)\right|^2 \operatorname{Im}\left(\chi^*(Q_1)\nabla\chi(Q_1)\right)}{\left|\phi(Q_1)\right|^2\left|\chi(Q_2)\right|^2 + \left|\phi(Q_2)\right|^2\left|\chi(Q_1)\right|^2}$$

$$\frac{\mathrm{d}Q_2}{\mathrm{d}t} = \frac{\frac{\hbar}{m_\mu}\left|\phi(Q_1)\right|^2 \operatorname{Im}\left(\chi^*(Q_2)\nabla\chi(Q_2)\right) + \frac{\hbar}{m_e}\left|\chi(Q_1)\right|^2 \operatorname{Im}\left(\phi^*(Q_2)\nabla\phi(Q_2)\right)}{\left|\phi(Q_1)\right|^2\left|\chi(Q_2)\right|^2 + \left|\phi(Q_2)\right|^2\left|\chi(Q_1)\right|^2}.$$

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assume: disjoint support of ϕ and χ.

$\rightarrow$ standard and symmetrized laws coincide.

$\rightarrow$ same trajectories.

initial positions $\rightarrow$ particle species.

Empirical Equivalence

in general different trajectories from BM's.

same statistical predictions.

empirically equivalent to BM and QM.

$\rightarrow$ shapes of trajectories "irrelevant" for the empirical predictions.

$\rightarrow$ measurement = measurement of positions.

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primitive ontology cannot be derived from quantum formalism.

primitive ontology cannot be derived from experiment.

[1] D. Dürr. *Bohmsche Mechanik als Grundlage der Quantenmechanik*. Berlin: Springer, 2001.

[2] D. Dürr and S. Teufel. *Bohmian Mechanics: The Physics and Mathematics of Quantum Theory*. Berlin: Springer, 2009.

[3] D. Dürr, S. Goldstein, and N. Zanghì. *Quantum Physics without Quantum Philosophy*. Heidelberg: Springer, 2013.

[4] S. French and M. Redhead. Quantum physics and the identity of indiscernibles. *The British Journal for the Philosophy of Science*, 39(2):233–246, 1988.

[5] S. Goldstein, J. Taylor, R. Tumulka, and N. Zanghì. Are all particles identical? *Journal of Physics A: Mathematical and General*, 38(7):1567–1576, 2005.

[6] S. Goldstein, J. Taylor, R. Tumulka, and N. Zanghì. Are all particles real? *Studies in History and Philosophy of Modern Physics*, 36(1):103–112, 2005.

[7] K. Stierstadt. *Thermodynamik: Von der Mikrophysik zur Makrophysik*. Heidelberg: Springer, 2010.