Inequivalent Representations Do Not Undermine Realism about Particles

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Outline

1. Introduction: Causal Warrant for Particles
2. Inequivalent Representations and Underdetermination in QFT
3. Non-uniqueness of Particle Number due to Inequivalent Representations

Background: Scientific Realism and Causal Warrant

Two kinds of warrant for scientific realism (Egg 2012):

- In general, *Inference to the best explanation (IBE)* generates theoretical warrant.
- Some particularly strong instances of IBE generate causal warrant.

Criteria for causal warrant

Causal inference: The explanation has to be in terms of properties for which there is a clear notion of what it means to modify them.

Empirical adequacy: The explanation has to give an accurate account of what is observable.

Non-redundancy: It has to be the only (serious) explanation which does so.

Example: Causal Warrant for Atoms/Molecules

Early 20th century: Atomic hypothesis as the best explanation of various phenomena, but other explanations remained viable ($\rightarrow$ mere theoretical warrant).
Jean Perrin's work on Brownian motion (1908–11) endowed the atomic hypothesis with causal warrant:

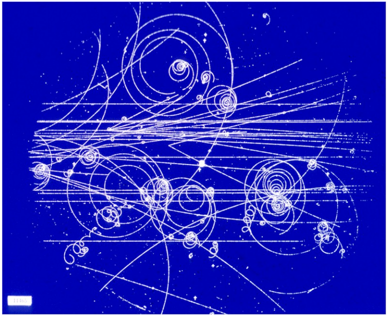
Causal inference: Perrin's theoretical models led to precise predictions depending on randomness of Brownian motion and on the value of Avogadro's number N_A.

Empirical adequacy: Experimental results agreed with the predictions for a particular value of N_A.

Non-redundancy: Although alternative explanations were available for each experiment determining the value of N_A, only the atomic hypothesis could account for *all* of them.

Realism about Subatomic Particles

In a similar way, particle physics experiments seem to give us causal warrant for realism about particles (i.e., localizable, countable entities, as described by the standard model of particle physics).



On the other hand, QFT seems to speak against such realism:

- No-go theorems concerning localizability (Reeh-Schlieder, Malament, Hegerfeldt etc.)
- Problems for countability due to non-existence or non-uniqueness of the number operator

Balancing Two Kinds of Warrant

Two opposing views on causal and theoretical warrant

1. When the two kinds of warrant pull in opposite directions, causal warrant trumps theoretical warrant.
2. Causal warrant does not hold any special status.

- An extreme version of 1, which completely disregards theoretical considerations (MacKinnon 2008), is implausible in light of experiment-theory interdependence.
- A moderate version of 1 is supported by case studies on scientific realism (e.g., Egg 2012).
- By contrast, the QFT-based case against particles seems to presuppose 2.
- Surprisingly, however, one version of this case turns out to be committed to 1.

Fraser vs. Wallace on Underdetermination in QFT

- Particle realism in a nutshell: The standard model of particle physics (based on QFT with renormalization and a finite cutoff, henceforth CQFT) is empirically successful, hence it is approximately true (by IBE).
- Fraser (2009, 2011): Underdetermination between CQFT and algebraic QFT (AQFT) invalidates this inference.
- Wallace (2011): Even if we accept Fraser's underdetermination claim (neglecting the fact that AQFT has as yet no realistic model in 3+1 dimensions), particle realism is not threatened if there is ontological continuity between AQFT and CQFT.
- Fraser: There is no such continuity, because AQFT admits unitarily inequivalent representations, whereas CQFT does not.

Fraser vs. Wallace on Inequivalent Representations

- Wallace: The inequivalent representations which distinguish AQFT from CQFT are associated with short-distance behaviour, and there we should not trust QFT anyway:

  > *Whatever our sub-Planckian physics looks like (string theory? twistor theory? loop quantum gravity? non-commutative geometry? causal set theory? something as-yet-undreamed-of?) there are pretty powerful reasons not to expect it to look like quantum field theory on a classical background spacetime. (Wallace 2011, 120–121)*

  This justifies the application of renormalization group methods in QFT, in analogy to condensed matter physics.
- Fraser: This analogy does not hold, because in the condensed matter case we have experimental evidence (Perrin!) for a discrete structure responsible for the breakdown of field theory at small distances.

Two Kinds of Evidence (Warrant) Revisited

Two opposing views on causal and theoretical warrant

1. When the two kinds of warrant pull in opposite directions, causal warrant trumps theoretical warrant.
2. Causal warrant does not hold any special status.

Intermediate Conclusion

For this argument against particle realism to go through, Fraser needs to admit that causal warrant trumps theoretical warrant (option 1 above). But this undermines AQFT-based arguments against particles in general.

Two Objections

1. Fraser's argument shows that there is actually no causal warrant for particles. Since AQFT promises to yield an alternative explanation of the relevant phenomena, the particle hypothesis fails to be non-redundant.

Reply: At present, AQFT does not explain the phenomena. If a future model of it does so, it will depend on the details if AQFT and CQFT fulfill the criteria for causal warrant to the same degree.

2. We have causal warrant merely for "particles" in a phenomenological sense, not a fundamental one.

Reply: CQFT's particle notion is not merely phenomenological, but does explanatory work. True, being explicitly non-fundamental, CQFT has nothing to say about fundamental ontology. By contrast, AQFT pretends to do so, but is merely one (incomplete) research program among others.

The Unruh Effect

Informal statement: Where an inertial observer in Minkowski spacetime detects a vacuum, a uniformly accelerated observer may detect an arbitrarily large number of (Rindler) quanta.

Formulation in terms of representation-independent probabilities:

$$P_{\Omega_M}(N_R \in [0, n]) = 0 \quad \text{for all } n \in \mathbb{N},$$

(Clifton and Halvorson 2001).

Formulation in terms of incommensurable particle notions: "There is no state to which Jack and Jill attribute different particle contents because any state to which one's particle notion applies is a state to which one the other's doesn't" (Ruetsche 2011).

Implications of the Unruh Effect?

The non-uniqueness of particle number only speaks against the reality of particles if one presupposes:

The no-privilege assumption

The Minkowski representation is not to be privileged over a Rindler representation.

- There are some theoretical reasons to question the no-privilege assumption (e.g., Rindler states do not fulfill the Hadamard condition), but these reasons are unconvincing (Ruetsche 2011, ch. 10).
- Another problem for the no-privilege assumption: There is causal warrant for Minkowski quanta, but not for Rindler quanta. Given the upshot of the Fraser-Wallace debate (above), this problem is serious.

Two Objections

1. Crude (and anthropocentric!) positivism; the fact that we are incapable of measuring Rindler quanta is ontologically insignificant!

Reply: Lack of causal warrant is not just due to incapacity for measurement, but due to lack of clarity what it would even mean to build a Rindler detector (Earman 2011, sec. 7).

2. Causal warrant only gives an epistemic privilege to the Minkowski representation, not an ontic one.

Reply: True, but given the present state of confusion about the ontology of quantum theory, one should avoid too wide a gap between epistemology and ontology.

Conclusion

A judicious balancing of causal warrant against theoretical warrant shows that the arguments from underdetermination and non-uniqueness are inconclusive.

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