Why we need philosophy of (quantum) physics

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0. Structure

1. Physics and Philosophy

2. Permutation Invariance and Indistinguishability

3. Permutation Invariance and Entanglement

1. Physics and Philosophy

Relationship physics and philosophy:

1) Physics as a challenge for philosophical theories

2) Philosophy as a service for (a better understanding of) physics

1. Physics and Philosophy

Concerning 1):

Philosophers develop and discuss, e.g., theories about *time*.

In order to be in accordance with modern physics, they also are interested in, e.g., the theories of relativity.

1. Physics and Philosophy

Concerning 2): Why physicists need philosophy …

a) because physics is somewhere inconsistent – e.g., the tension between GR and QFT (?)

b) because *standard* physics is somehow insufficient (?)

1. Physics and Philosophy

Concerning 2a): Physicists are working together with philosophers, e.g.,

i) establishing alternatives to standard quantum mechanics (Bohm; GRW)

ii) the search for a theory of quantum gravity

1. Physics and Philosophy

However, here the focus is on **2b)**:

Standard (quantum) physics is conceptually insufficient!

Paradigmatic case: Permutation Invariance (PermInv)

2. PermInv and Indistinguishability

Physically, PermInv seems to be sufficiently clear:

1) Restriction on the allowed *operators*, the symmetric ones, such as:

$$\hat{O} = \left(\hat{R}\widehat{s_y}\right) \otimes \hat{1} + \hat{1} \otimes \left(\hat{R}\widehat{s_y}\right)$$

2. PermInv and Indistinguishability

2) Restriction on the allowed *states*, the (anti-)symmetric ones, such as:

$$|\Psi\rangle = {}^{1}/_{\sqrt{2}}\,(|\mathrm{R}\rangle_1|{\downarrow_z}\rangle_1|\mathrm{L}\rangle_2|{\uparrow_z}\rangle_2 - |\mathrm{L}\rangle_1|{\uparrow_z}\rangle_1|\mathrm{R}\rangle_2|{\downarrow_z}\rangle_2)$$

2. PermInv and Indistinguishability

Nonetheless, PermInv is conceptually unclear:

1) Physicists are talking about ‘identical’ particles, but they don’t intend to say that these particles are *numerically* identical. (irrelevant)

2. PermInv and Indistinguishability

2) Physicists are talking about ‘indistinguishable’ particles, but it is questionable if they really intend to say that particles are *utterly* indiscernible.

3) Still, physicists avoid talking simply about ‘similar’ particles …

2. PermInv and Indistinguishability

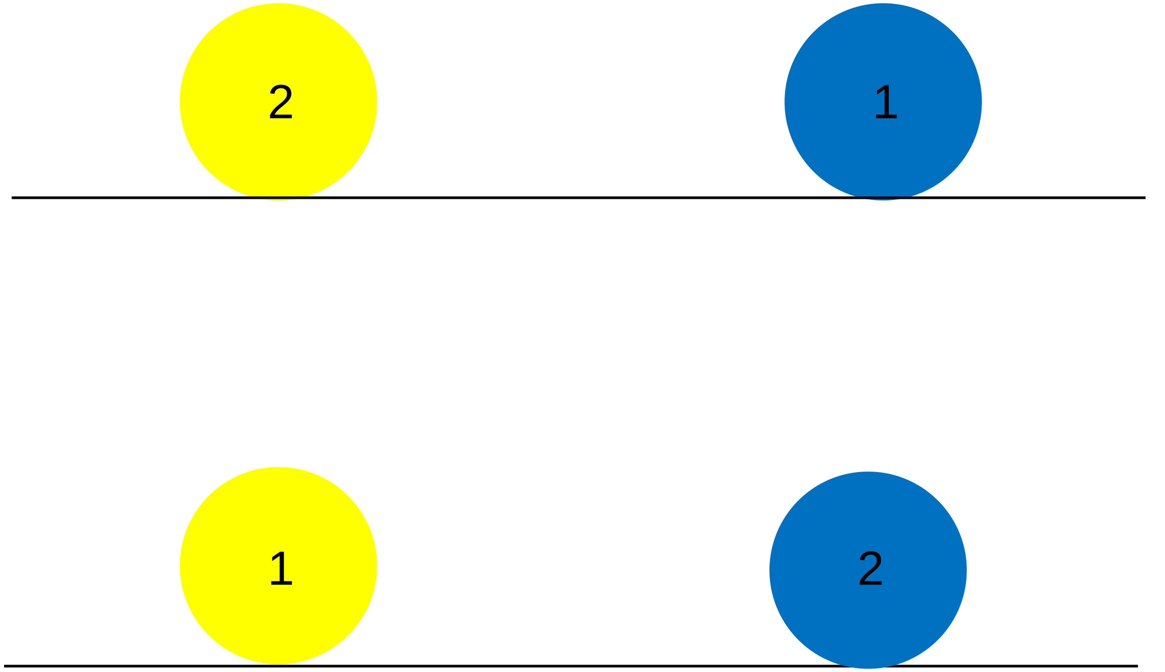
The problem has two aspects:

1) Usually, ‘PermInv’ is understood in a different way than it is in QM.

2) Usually, ‘PermInv’ is not sufficiently distinguished from ‘entanglement’.

2. PermInv and Indistinguishability

2. PermInv and Indistinguishability



2. PermInv and Indistinguishability

The usual idea of ‘PermInv’ is:

There *are* qualitatively distinguishable objects, e.g., one is yellow, the other blue.

Two qualitatively indistinguishable *situations* have to be identified.

2. PermInv and Indistinguishability

Applied to QM, this implies:

The states are non-symmetric product states, such as: $|\Psi\rangle = |\mathrm{R}\rangle_1 |\downarrow_z\rangle_1 |\mathrm{L}\rangle_2 |\uparrow_z\rangle_2$

The two product states:

$|\mathrm{R}\rangle_1 |\downarrow_z\rangle_1 |\mathrm{L}\rangle_2 |\uparrow_z\rangle_2$ and $|\mathrm{L}\rangle_1 |\uparrow_z\rangle_1 |\mathrm{R}\rangle_2 |\downarrow_z\rangle_2$

have to be identified.

2. PermInv and Indistinguishability

By contrast, this is *not* what happens in QM!

Instead, the required state is completely different, namely:

$$|\Psi\rangle = {}^{1}/_{\sqrt{2}}\,(|\mathrm{R}\rangle_1|\downarrow_z\rangle_1|\mathrm{L}\rangle_2|\uparrow_z\rangle_2 - |\mathrm{L}\rangle_1|\uparrow_z\rangle_1|\mathrm{R}\rangle_2|\downarrow_z\rangle_2)$$

2. PermInv and Indistinguishability

That state does not allow the given interpretation!

Instead, both particle 1 and particle 2 are in the *same* state, namely in:

$$\hat{\rho}_{1;2} = \frac{1}{2}|\mathrm{L},\uparrow_z\rangle\langle\mathrm{L},\uparrow_z| + \frac{1}{2}|\mathrm{R},\downarrow_z\rangle\langle\mathrm{R},\downarrow_z|$$

2. PermInv and Indistinguishability

The particles *share* the same (mixed) state, so *they* – and not merely the situations – are indistinguishable.

Particles (bosons *and* fermions) of the same kind *always* are utterly indistinguishable, though numerically distinct.

2. PermInv and Indistinguishability

QM-objects *violate*, in principle, Leibniz's Law of the Identity of Indiscernibles:

$$\forall F\ (F(x) \leftrightarrow F(y)) \Rightarrow x = y$$

"Indistinguishable objects are identical; numerically distinct objects are distinguishable."

3. PermInv and Entanglement

Second aspect: PermInv should be distinguished from entanglement.

$$|\Psi\rangle = {}^{1}/_{\sqrt{2}}\,(|\mathrm{R}\rangle_1|{\downarrow_z}\rangle_1|\mathrm{L}\rangle_2|{\uparrow_z}\rangle_2 - |\mathrm{L}\rangle_1|{\uparrow_z}\rangle_1|\mathrm{R}\rangle_2|{\downarrow_z}\rangle_2)$$

only expresses PermInv but *not* physical entanglement.

3. PermInv and Entanglement

With such a state one cannot violate Bell-inequalities. By contrast:

$$|\Psi\rangle = {}^{1}/_{\sqrt{2}}\,(|\uparrow\rangle_1|\downarrow\rangle_2 - |\downarrow\rangle_1|\uparrow\rangle_2)(|\mathrm{R}\rangle_1|\mathrm{L}\rangle_2 + |\mathrm{L}\rangle_1|\mathrm{R}\rangle_2)$$

also expresses physical entanglement.

References:

- Ghirardi, G., L. Marinatto und T. Weber (2002). Entanglement and properties of composite quantum systems: A conceptual and mathematical Analysis. *Journal of Statistical Physics* 108: 49-122.

- Ghirardi, G. und L. Marinatto (2003). Entanglement and properties. *Fortschritte der Physik* 51: 379-387.

3. PermInv and Entanglement

With this distinction in mind, GMW describes the purely PermInv-states as follows:

"[T]here is a particle with spin up along z-axis and located in region *R* and [...] there is a particle with spin down along z-axis and located in region *L*." (Ghirardi and Marinatto 2003, 384).

3. PermInv and Entanglement

So, according to GMW, there are – as previously expected but in contradiction to mainstream QM-interpretation – *two qualitatively distinguishable* particles in such states.

However, theses particles cannot be those labelled by ‘1’ and ‘2’! *They* would be in the same mixed state, as argued.

3. PermInv and Entanglement

As it seems, within such a state:

$$|\Psi\rangle = {}^{1}/_{\sqrt{2}}\,(|\mathrm{R}\rangle_1|\downarrow_z\rangle_1|\mathrm{L}\rangle_2|\uparrow_z\rangle_2 - |\mathrm{L}\rangle_1|\uparrow_z\rangle_1|\mathrm{R}\rangle_2|\downarrow_z\rangle_2)$$

the adequate labels – instead of ‘1’ and ‘2’ – are something like:

“[q_e, m_e, ½; R, $\downarrow_z$]” and “[q_e, m_e, ½; L, $\uparrow_z$]”

3. PermInv and Entanglement

Concerning *entangled* states, by contrast, one is inclined to say that particle 1 is entangled with particle 2 – in the way that it is not possible to attribute any definite spatial property nor any definite spin property to each particle.

Otherwise, only the whole can be labelled analogously to the PermInv-states.

3. PermInv and Entanglement

Within such a state:

$$|\Psi\rangle = {}^{1}/_{\sqrt{2}}\,(|\uparrow\rangle_1|\downarrow\rangle_2 - |\downarrow\rangle_1|\uparrow\rangle_2)(|\mathrm{R}\rangle_1|\mathrm{L}\rangle_2 + |\mathrm{L}\rangle_1|\mathrm{R}\rangle_2)$$

the adequate label – instead of ‘1’ and ‘2’ – would be:

“[2q_e, 2m_e, s = 0; R – L, m = 0]“

3. PermInv and Entanglement

The tension between purely PermInv-states and physically entangled states seems to be:

The tensor product indices ‘1’ and ‘2’ *do* refer to physical particles in the latter case but do *not* refer to physical particles in the former case.

3. PermInv and Entanglement

That is the *labelling problem* in QM.:

More generally, the (interpretive, philosophical) question is: How to refer to objects in the quantum domain?

Reference problem: Do we need philosophy of language in order to fully understand the Hilbert space formalism?

4. Announcement

Kolloquium in *Theoretical Philosophy*:

Thursdays, 16ct, AR-NB 017

Sometimes, research papers in philosophy of physics will be discussed, e.g., 21st June and 28th June …

Thanks!