The Higgs mechanism as a philosophical challenge

Simon Friederich
Philosophisches Seminar
Universität Göttingen

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Why philosophy?

The Higgs mechanism (HM) challenges philosophy of science in different ways:

- Conceptually: What is the conceptual core of the HM, what is metaphor?
- Ontologically: What does the HM tell us about reality?
- Methodologically: Is the HM methodologically sound by the standards of philosophy of science? (Think of physicists' "Bauchschmerzen" concerning the HM!)

My aim: highlight some aspects of the first and third challenge.

Outline of the Presentation

The HM and gauge symmetry breaking

- The Standard Model is a *gauge* quantum field theory (gauge group $SU(3) \times SU(2) \times U(1)$).
- Spontaneous gauge symmetry breaking is conceptually crucial for the HM.

So let's ask:

- What are gauge symmetries?
- What is spontaneous gauge symmetry breaking?

Gauge symmetries

- Example: $A_\mu(x) \mapsto A_\mu(x) + \partial_\mu \chi(x)$.
- Crucial: Configurations related by gauge transformations are physically identical.
- Consequence: Gauge symmetry as descriptive redundancy.
- Contrast: Galileo's ship at rest and in motion are physically different, though empirically equivalent (from within).

Challenge for philosophy:

- Can this contrast be made precise? (intense debate among philosophers)
- My view: What makes gauge symmetries non-empirical is that they can always be extended trivially towards infinity.

What is spontaneous symmetry breaking?

Roughly:

- Symmetry of the Lagrangian *radically absent* from the state of the system.
- Necessary condition: infinitely many degrees of freedom.

Gauge symmetry breaking?

But what does “breaking a descriptive redundancy” mean?

- Chris Smeenk: “If gauge symmetry merely indicates descriptive redundancy in the mathematical formalism, it is not clear how spontaneously breaking a gauge symmetry could have any physical consequences, desirable or not.”
- Short answer: Gauge symmetry breaking has indeed no physical consequences.
- In particular: Mass generation not *due to* symmetry breaking...
- ... but the concept “spontaneous symmetry breaking” is useful for the heuristics of the HM.

The HM and broken gauge symmetry I

Classically:

- Minimum energy configurations of Higgs model not gauge invariant ($\langle\phi\rangle \neq 0$).
- But: Nature does not “choose” among them.
- They are all physically equivalent.

The HM and broken gauge symmetry II

Quantum:

- Local gauge symmetry *not* broken at all (Elitzur).
- (Post gauge-fixing) Global gauge symmetries may be spontaneously broken.
- But their breaking does not line up with Higgs/non-Higgs phase transitions.
- So, gauge symmetry breaking is *not* the hallmark of Higgs phases.

Where does this leave us?

- Gauge symmetry breaking in the HM not a feature of nature.
- Symmetry breaking is *conceptually* crucial for the HM, not *causally*.

More details: S. Friederich, “Gauge symmetry breaking in gauge theories—in search of clarification”, EJPS, 2012

The *ad hoc*-charge against the HM

Not everyone is in all respects happy with the HM:

- “ad hoc introduction of scalar fields” (Slavnov)
- “ad hoc quality to how [symmetry breaking] is realized” (Smolin)
- “ad hoc extension [of the SM]” (Jackiw)
- “frightfully ad hoc” (Giudice)
- “as physicists, we should be ashamed of ourselves if we are satisfied with this” (Peskin)
- “Of course our model has too many arbitrary features for these predictions to be taken very seriously.” (Weinberg 1967)

For more details on what follows: see manuscript by S. Friederich, R. Harlander, and K. Karaca, in preparation.

What's the problem?

Criticisms of the HM:

- insufficient evidence
- no other fundamental scalars
- fundamental scalars have ugly consequences (naturalness...)
- symmetry breaking non-dynamical

Philosophers on the *ad hoc*

Philosophers have proposed *definitions* of "adhocness" (e.g. Popper, Schaffner, Grünbaum, Leplin).
Basic ideas:

- Ad hoc-hypotheses are invoked to rescue a theory from refutation.
- They cure the problems of a theory only superficially.
- They are therefore methodologically problematic.

Examples: Lorentzian length contraction, neutrino hypothesis, trans-uranian planet hypothesis, wave collapse, Bohr model, ...

Philosophers on the *ad hoc* I

Do the philosophical accounts of “adhocness” apply to the HM?
Partly, yes:

- Leplin: Ad hoc-hypotheses are based on insufficient *independent* evidence.
- Seems plausible for the HM prior to Higgs-discovery.

Philosophers on the *ad hoc* II

- Leplin: Ad hoc-hypotheses are *tentative*.
- HM (with fundamental scalar) often seen as merely an “effective” description.

- Leplin: Ad hoc-hypotheses are *non-fundamental*.
- Naturalness problem seems to indicate that new physics (more fundamental) sets in at TeV(?)-scale.

Philosophers on the *ad hoc* III

However: All philosophers seem to agree that

- Ad hoc-hypotheses are invoked to rescue an *existing* theory (held by some scientists) from falsification.
- Arguably, this does not apply to the HM.

So, HM conforms/fails to conform to philosophers' accounts in an interesting way!

Summary/Conclusion

My main claims:

- Gauge symmetries differ from other symmetries in that they connect physically identical states.
- The notion of a spontaneously broken gauge symmetry is conceptually – but not causally! – crucial for the HM.
- The HM is in an interesting way *ad hoc*/*non-ad hoc* according to philosophers' criteria of adhocness.