

The Higgs mechanism as a philosophical challenge

Simon Friederich
Philosophisches Seminar
Universität Göttingen

06.03.2013 / Desden

Introduction

Gauge symmetries
and their breaking

Is the Higgs
mechanism ad
hoc?

Conclusion

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.

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Outline of the Presentation

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The HM and gauge symmetry breaking

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- ▶ 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?

- ▶ 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.

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What is spontaneous symmetry breaking?

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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 Higgs mechanism and broken gauge symmetry I

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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.

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 have proposed *definitions* of “ad hocness” (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, ...

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Do the philosophical accounts of “ad hocness” 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.

- ▶ 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.

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!

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.