Dualities, intertheoretic relations and ontological democracy

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Dualities: philosophical reflections

The general issue:

The philosophical *significance* and *impact* of a 'fact', i. e. ,

the relevance of dualities in contemporary (theoretical) physics.

General reflections

Physical dualities in general:

- The meaning of a physical duality (dualities and symmetries)
- What kinds of dualities? In which contexts?
- How are they applied in physics? Which role they cover? (dualities and analogies)

Dualities and traditional philosophical issues

The impact of physical dualities on traditional issues in the philosophy of science.

In particular:

- The issue of intertheoretic relations
- The 'question of physical objects'

Underlying:

- The fundamentality issue (What is fundamental?)

The fundamentality issue

Received view (dominant in the 1970s and 1980s and still widely accepted):

Fundamental physics is the physics concerned with the search for the *ultimate constituents* of the universe and the laws governing their behaviour and interactions.

Fundamentalism:

- there is a fundamental level of reality (fundamental physical objects)
- there is a fundamental physical description in terms of laws (fundamental theory)

Fundamentalism, reductionism, ...

Common associations:

Fundamentalism $\rightarrow$ Reductionism

Anti-fundamentalism $\rightarrow$ Anti-reductionism

Related *debated issues* (by both philosophers and scientists, with different motivations):

Inter-theory relations, hierarchy of levels (levels of organization/levels of description), part/whole relation, the fact of emergence (P. W. Anderson, 1972), the relevance of scales (the implication of the effective field theory approach), ...

Intertheoretic relations: the traditional debate

The general issue:

Assuming a **level structure** of *units* of some kind (theories, concepts, entities, properties, ...), how are the units related?

More specifically:

Is the relation of the units on level L_{i+1} (coarser) to the units on level L_i (finer) better described in terms of:

reduction to , supervenience on, emergence from?

Notice: in the cases usually discussed, the theories considered are either a) on the same level ($\rightarrow$ *intra-level relations)*, or b) on successive levels ($\rightarrow$ *intra-level relations)*.

Fundamental objects

Received view:

the physical 'objects' populating the fundamental level of reality (the *basic constituents* of everything).

In the *Standard Model* for particle physics:

the so-called elementary particles.

$\rightarrow$ an apparently natural connection between fundamental and elementary, as attributes referred to the objects of physics.

(Fundamental) Elementary/Composite

Fundamental: *x* is a fundamental entity iff *x* does not depend for its existence on the existence of other entities (fundamentality in the sense of *ontological independence*).

Elementary: structureless (non composite)

$\Rightarrow$ it is quite natural to assume that what is *elementary* is a better candidate for being a fundamental object than what is *composite*.

Strong-weak coupling dualities

Duality conjectures

– generalizing the idea of Dirac's (1931, 1948) theory of electric-magnetic (E-M) duality to non-Abelian gauge theories (Montonen-Olive, 1977), supersymmetric field theories and string theories (S-duality) –

which state that there is an *equivalence map* between apparently different theoretical descriptions in such a way that

- the weak coupling region of the one theory is mapped to the strong coupling region of the second theory and vice versa,

- the elementary particles ('electric charges') of the one theory are mapped to composite particles '(solitons' or 'magnetic charges' of the other theory).

thus "bringing in a sort of democracy between all particles, elementary and composite" (A. Sen, 1996).

Historical ‘analogy’

The case of the DHS (Dolen-Horn-Schmid) duality, also known as ‘dual bootstrap’, at the core of the *dual models* from which early string theory was born between the late Sixties and the early Seventies.

The context: the so-called *S*-matrix approach to describing the physics of strong interactions in the 1960s.

Motivation: the difficulties arising in a field theoretic description of strong interactions.

Aim (inspired by earlier work of Heisenberg): determining the relevant observable physical quantities, namely, the scattering amplitudes (which formed the elements of the *S*-matrix) on the basis of general principles such as *unitarity*, *analyticity* and *crossing symmetry*, and a minimal number of additional assumptions.

DHS duality

The assumption ('duality principle') by Dolen, Horn and Schmid (1967), suggested by the experimental data, that

the contributions from *resonance intermediate states* and from *particle exchange* each formed a complete representation of the scattering process

(so that they should not be added to one another in order to obtain the total amplitude).

In terms of the *Mandelstam's variables* and in the framework of the so-called *Regge theory*:

the duality principle (as initially stated) established direct relations between a low-energy and a high-energy description of the hadronic scattering amplitude $A(s,t)$, namely:

the low-energy description in terms of direct-channel resonance poles (the contributions from resonance intermediate states), and

the high-energy description in terms of the exchange of so-called Regge poles in the crossed-channel (the contributions from particle exchange)

could each be obtained from the other by analytic continuation (and, thus, each formed a complete representation of the scattering process).

The ‘dual boostrap’

The duality principle was seen to represent an effective implementation of two (connected) ideas defended, in particular, by *Geoffrey Chew* and his school:

• the idea of nuclear democracy — no hadron is more fundamental than the others),

• the bootstrap idea — the idea of a self-consistent hadronic structure in which the entire ensemble of hadrons provided the forces (by hadron exchange) making their own existence (as intermediate states) possible.

Physical objects:

A **structural** (realist) constructivist approach?

Our objectifying pattern

We are prone to talk and think of objects. Physical objects are the obvious illustration [...]. We persist in breaking reality down somehow into a multiplicity of identifiable and discriminable objects, to be referred to by singular and general terms. We talk so inveterately of objects that to say we do so seems almost to say nothing at all [...].

W. V. QUINE, "Speaking of Objects" [1957], 1958