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The uses of isospin in early nuclear and particle physics

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ABSTRACT

This paper reconstructs the early history of isospin up to and including its employment in 1951–52 to conceptualize high-energy pion-proton scattering. Studying the history of isospin serves as an entry point for investigating the interplay of theoretical and experimental practices in early nuclear and particle physics, showing the complexity of processes of knowledge construction which have often been presented as straightforward both in physicists' recollections and in the historiography of science. The story of isospin has often been told in terms of the discovery of the first "intrinsic property" of elementary particles, but I will argue that the isospin formalism emerged and was further developed because it proved to be a useful tool to match theory and experiment within the steadily broadening field of high-energy (nuclear) physics. Isospin was variously appropriated and adapted in the course of two decades, before eventually the physical-mathematical implications of its uses started being spelled out. The case study also highlights some interesting features of high-energy physics around 1950: the contribution to post-war research of theoretical methods developed before and during the war, the role of young theoretical post-docs in mediating between theorists and experimenters, and the importance of traditional formalisms such as those of spin and angular momentum as a template both for formalizing and conceptualizing experimental results.

1. A tool, not a property: isospin and the historiography of particle physics

In the 1930s the spin-like formalism which we today associate with the notion of "isospin" was introduced in context of research on atomic nuclei, and in the early 1950s it was used for conceptualizing particle interactions at what for the time were the highest energies accessible to experiment. This story has been often told in terms of the "discovery" and "confirmation" of isospin as the first "intrinsic property" of elementary particles (Brown, 1988; Kemmer, 1982, 1983; Rasche, 1971). In my paper I will look more closely at these developments, approaching the emergence of isospin not as a part of the history of intrinsic properties, as it appears a posteriori, but as a standalone episode. The case study will show how the idea that the above-mentioned spin-like formalism represented an "intrinsic property" of particles played no role in these developments up to and including the events of the early 1950s. On the grounds of my analysis I will argue that isospin was a valuable, multiform tool of theoretical practices which, in the early days of nuclear and particle physics, various scientists appropriated and adapted in a complex process of producing contact between theoretical and experimental research. Although the core of the symbolic formalism has remained essentially unchanged from its inception until today, in the first decades of its existence it was put to work to such different aims and in such different contexts that it acquired various layers of situated physical-mathematical implications that could carry over from one context of use to another. Although it is tempting to read into these developments the "discovery" of isospin as an intrinsic particle property, we should be weary to do so, and I will approach these historical constellations by asking which elements of today's complex notion of isospin were (or were not) actually expressed by historical actors, and how they were (or were not) employed to achieve specific goals. This methodology will allow to appreciate how epistemic developments which appear straightforward today actually required great originality and effort at the time they occurred.

To properly approach the subject at hand it is important to be aware of how much today's notion of isospin is entangled with the world-view shaped by the so-called "Standard Model", a theory which emerged in the 1970s and has since that time provided the basis for an increasing number of successful predictions of particle

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phenomena. Much has been written about how the Standard Model emerged and came to dominate high energy physics, while the history of particle physics in the 1950s and 60's is usually presented as a rather chaotic enterprise dominated by a steadily increasing influx of experimental results which theorists struggled to embed in a coherent framework.[1] However, most of the conceptual and mathematical components of the Standard Model were developed long before its emergence and only a posteriori embedded into it. Among them were both refined mathematical constructs like local gauge invariance and apparently simple ideas like the notion of intrinsic properties.[2]

Intrinsic properties are also known today as "internal quantum numbers" or "generalized charges" and, despite their apparent simplicity, they constitute a complex physical-mathematical construct which is deeply embedded in the conceptual framework centered on the Standard Model. Within that framework, each intrinsic property is associated with a given mathematical invariance (a "symmetry") of the Standard Model equations, and from this symmetry it is possible to formally derive both the "conservation" of the property and a number of "selection rules" stating which particle processes are or are not compatible with the validity of the symmetry and of the relevant conservation.[3] The numerical value of an intrinsic property like isospin cannot be directly measured, and only selection rules provide testable predictions of its conservation. Despite this fact, intrinsic properties are today conceived as physically conserved quantities fully analogous to macroscopically measurable ones like electric charge or energy. It is not my intention to analyze here further this conceptual construct, but it is important to understand how deeply the notion of intrinsic property is today shaped by the Standard-Model world-view, because this fact has had consequences for the historiography of particle physics. Historians have paid little attention to the emergence of intrinsic properties, and one reason for this neglect is that, within the Standard Model world-view, it is difficult to conceive elementary particles as distinct from their various intrinsic properties which determine both the identity of the particles and the features of their mutual interactions. Accordingly, it is today easy to regard intrinsic properties as something which can be more or less directly "discovered" by observing the way in which particles mutually interact, but in the early days of high energy physics conceptualizing an observed phenomenon in terms of "particles", "properties" and "interactions" was a highly non-trivial process of co-construction of all notions involved[4]. Moreover, all intrinsic properties are today embedded in the Standard Model in very similar ways, and so it is easy to conceive their processes of emergence as a series of distinct, but historically analogous narratives. However, the empirical material today regarded as observable manifestation of the various intrinsic properties is often of radically different kind, and conceptualizing it according to similar templates was in no way straightforward.

To try and redress the balance, in the following pages I will explore the modes, goals and contexts of the introduction and employment of the spin-like formalism today known as isospin, reconstructing the functions it played at different stages of its evolution, and arguing that it constituted a physically vague, but heuristically fruitful tool for matching theory and experiment first in early nuclear research, and then in early particle physics. Despite its importance as a theoretical instrument, in this period the isospin formalism was not regarded as representing a new property of matter. The history of isospin is an extremely fragmented one, and reconstructing it brings to light how much epistemic developments in early particle physics were shaped by situated constellations in which theorists set themselves the goal of providing a tentative, qualitative or quantitative match for specific experimental results. At these junctures scientists employed those among the available theoretical tools which best suited their skills and aims, appropriating, extending and reinterpreting them according to their own needs. The isospin formalism could be a very valuable instrument for many reasons: it provided an often needed additional degree of freedom when fitting formulas to match empirical results; it allowed to establish formal analogies between different physical systems, importing theoretical techniques from other areas into (sub)nuclear physics; it was formally identical to the traditional spin formalism, and so it could be manipulated along familiar guidelines; finally, the isospin formalism seemed to come with little or no strings attached in terms of physical interpretation: it appeared as a simple mathematical trick which could be unproblematically embedded in many different conceptual frameworks. Physicists started becoming aware of the physical implications of the uses of isospin only in the course of the 1950s, and even then speaking of isospin as a "good quantum number" for nuclear and meson interactions still did not seem to imply regarding it as an intrinsic property of matter.

To support the view sketched above, in the following sections I will offer detailed analyses of the various historical constellations in which isospin was used in the first two decades after its coming-to-be. In Section 2 I will discuss the introduction by Heisenberg in 1932 of a spin-like formalism to describe protons and neutrons in atomic nuclei, closely looking at the way he did (or did not) use it and revising some opinions expressed in historiography. I will then describe the employment and expansion of that formalism before the second world war both in the study of nuclear structure (Section 3.1) and in meson theories of nuclear interactions (Section 3.2). Section 4 of the paper is devoted to discussing how, in the early 1950s, isospin became a very productive, formally sharper if physically vaguer heuristic tool for finding a quantitative match between theory and experiment. Summary and conclusions are offered in Section 5.

2. Werner Heisenberg's introduction of ρ-spin

Contrary to what is often the case in the history of science, the origin of isospin can be unambiguously pinpointed by tracing it back to Werner Heisenberg's trilogy of papers on nuclear forces published in 1932-33.[5] The ideas put forward in those papers were innovative and influential, but at the same time also rather cryptic and their interpretation has been the subject of some discussion among historians. It is not my intention to offer here a full analysis

[1] On the emergence of the Standard Model see for example: Hoddeson et al. (1997). Experimental developments in the pre-Standard Model era have been analyzed for example in Franklin (1989, 1990); Galison (1997). The main historical studies on pre-Standard Model theory are devoted to a small number of specific issues, such as: Cushing (1990) (S-matrix theory), Kaiser (2005) (Feynman diagrams), Schweber (1994) (QED).

[2] On gauge invariance see O'Raifeartaigh (1997), on intrinsic properties Borrelli (2015).

[3] For a more detailed discussion of how the notion of intrinsic property today is linked to a complex physical- mathematical construct comprising mathematical invariance, physical conservation and selection rules see: Borrelli (2015), on which the following remarks are based.

[4] For simplifying statements on the origin of isospin and other intrinsic properties, see for example: Galison (1997), 43, Pickering (1984), 54, Schweber (2002), 280. I refer to these passages in particular because they were written not by physicist recollecting their past work, but by outstanding historians of particle physics, and as such may best count as evidence of a blind spot in historiography.

[5] The following overview is based on the original sources and on the following literature: Brown (1988, 1995), Brown and Rechenberg (1996), Carson (1996a, 1996b), Darrigol (1988), Kemmer (1982, 1983) and Rasche (1971).