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Essay review

Avoiding reification
Heuristic effectiveness of mathematics and the prediction of the Ω^- particle

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ABSTRACT

According to Steiner (1998), in contemporary physics new important discoveries are often obtained by means of strategies which rely on *purely formal* mathematical considerations. In such discoveries, mathematics seems to have a peculiar and controversial role, which apparently cannot be accounted for by means of standard methodological criteria. M. Gell-Mann and Y. Ne'eman's prediction of the Ω^- particle is usually considered a typical example of application of this kind of strategy. According to Bangu (2008), this prediction is apparently based on the employment of a highly controversial principle—what he calls the "reification principle". Bangu himself takes this principle to be methodologically unjustifiable, but still indispensable to make the prediction logically sound. In the present paper I will offer a new reconstruction of the reasoning that led to this prediction. By means of this reconstruction, I will show that we do not need to postulate any "reificatory" role of mathematics in contemporary physics and I will contextually clarify the representative and heuristic role of mathematics in science.

1. Introduction

In his Steiner (1998) famous book, Mark Steiner argues that the role of mathematics in contemporary physics is peculiar. According to him, very often contemporary physicists draw important consequences about the physical world by relying on *purely formal* mathematical considerations, or 'analogies', which seem not to be in any sense rooted in the *content* of the mathematical representations. In this sense, the applicability of mathematics turns out to be 'magic' or—as Wigner (1960) would have put it —'miraculous'.[1]

Among the examples offered by Steiner in support of his thesis, Gell-Mann and Ne'eman's discovery of the Ω^- particle in 1962 is one of the most interesting. What is relevant in this discovery is the fact that the prediction of this new physical entity seems to be motivated *only* by the mathematics employed (the theory of irreducible group representations).[2] According to Steiner, this is an interesting example of analogy reasoning in physics, but he does not enter into the details of the prediction. A detailed analysis of this example is offered by Bangu, first in his Bangu (2008) article and then in his Bangu (2012) book. Bangu argues that the prediction of the Ω^- particle relies on a methodological principle, which he calls the "reification principle".[3] This principle is not justifiable by means of our standard methodological criteria, and Bangu himself takes this principle to be highly problematic.

I will offer a new logical reconstruction of the prediction of the Ω^- particle that *does not rely*, in any sense, on the reification

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[1] Steiner himself justifies the appropriateness of the word "magic" in this context: ⋞ Expecting the forms of our notation to mirror those of (even) the atomic world is like expecting the rules of chess to reflect those of the solar system. I shall argue, though, that some of the greatest discoveries of our century were made by studying the symmetries of notation. Expecting this to be any use is like expecting magic to work ⋟ (Steiner, 1998, p. 72).

[2] As it will become clearer later, this does not amount to saying that *no empirical fact* played a role in shaping the prediction. What Steiner is stressing here, is that the *justification* for the prediction seems to be purely mathematical—namely, purely based on the mathematical formalism employed.

[3] In Bangu (2012) the principle is called "identity principle", but the shift of terminology does not change the substance of his argument. Since no argument is offered to motivate the latter terminology over the first, I will refer to this principle by means of the first terminology, since I think is less ambiguous.

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1355-2198/

principle (neither explicitly, nor in disguise). This alternative reconstruction will be based on some considerations about the representative role of mathematics and on the heuristic effectiveness that representing mathematical structures may exhibit under some conditions. I will firstly present Bangu's reconstruction of the reasoning that led Gell-Mann and Ne'eman to their prediction (Section 2), and I will underline some difficulties in it (Sections 3.1 and 3.2). In order to solve these difficulties, I will introduce a general account for mathematical representativeness (Section 3.3), and then I will discuss under which conditions mathematics can play a heuristic role in science (Section 3.4). Within this framework, I will offer a way to account for Gell-Mann and Ne'eman's reasoning *without relying on Bangu's reification principle*.

2. The discovery of the Ω^- particle: existential predictions and the reification principle

2.1. Bangu's reconstruction

Bangu's reconstruction of the Gell-Mann and Ne'eman predictive reasoning (hereafter, GMNPR) is based on the detailed account given by Ne'eman. Here is the whole passage to which Bangu referred.

In 1961 four baryons of spin $\frac{3}{2}$ were known. These were the four resonances $\Delta^-, \Delta^0, \Delta^+, \Delta^{++}$ which had been discovered by Fermi in 1952. It was not clear that they could not be fitted into an octet, and the eightfold way predicted that they were part of a decuplet or of a family of 27 particles. A decuplet would form a triangle in the $S-I3$ [strangeness-isospin] plane, while the 27 particles would be arranged in a large hexagon. (According to the formalism of SU (3), supermultiplets of 1, 8, 10 and 27 particles were allowed.) In the same year (1961) the three resonances $\Sigma(1385)$ were discovered, with strangeness -1 and probable spin $\frac{3}{2}$, which could fit well either into the decuplet or the 27-member family.

At a conference of particle physics held at CERN, Geneva, in 1962, two new resonances were reported, with strangeness -2, and the electric charge -1 and 0 (today known as the $\Xi(1530)$). They fitted well into the third course of both schemes (and could thus be predicted to have spin $\frac{3}{2}$). On the other hand, Gerson and Shoulamit Goldhaber reported a failure: in collisions of K^+ or K^0 with protons and neutrons, one did not find resonances. Such resonances would indeed be expected if the family had 27 members. The creators of the eightfold way, who attended the conference, felt that this failure clearly pointed out that the solution lay in the decuplet. They saw the pyramid [in Fig. 1] being completed before their very eyes. Only the apex was missing, and with the aid of the model they had conceived, it was possible to describe exactly what the properties of the missing particle should be! Before the conclusion of the conference Gell-Mann went up to the blackboard and spelled out the anticipated characteristics of the missing particle, which he called omega minus (because of its negative charge and because omega is the last letter of the Greek alphabet). He also advised the experimentalists to look for that particle in their accelerators. Yuval Neeman had spoken in a similar vein to the Goldhabers the previous evening and had presented them in a written form with an explanation of the theory and the prediction. (Ne'eman & Kirsh, 1996, pp. 202–203)

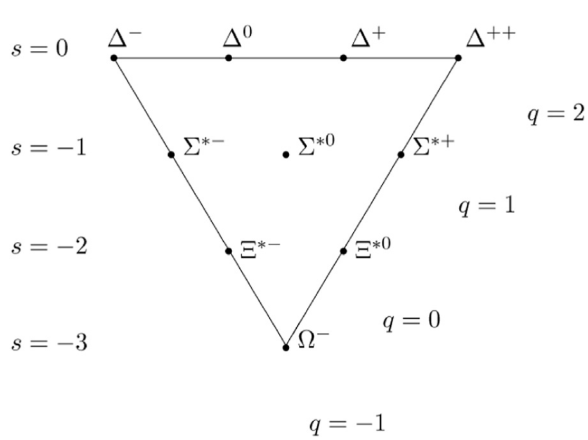

Fig. 1. Spin-$\frac{3}{2}$ baryon decuplet. Credits: http://math.ucr.edu/home/baez/diary/march_2007.html.

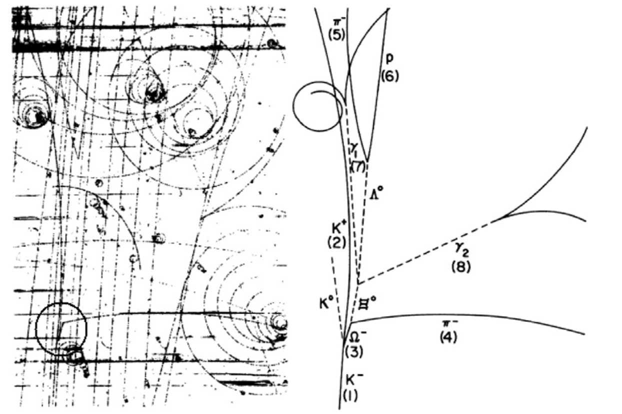

Fig. 2. Photograph (left side) and line diagram (right side) of the decay of an Ω^- particle in a bubble chamber. The short track of the Ω^- particle is highlighted by the circle in the low left corner. Credits: Barnes et al. (1964) (Brookhaven National Laboratories).

When a few years later, in 1964, experimentalist physicists looked for the Ω^- particle in their accelerators, they found out exactly what Gell-Mann and Ne'eman predicted: the particle exists and it has exactly the predicted characteristics (see Fig. 2).[4]

Now, one might ask: Why did the experimentalist physicists trust Gell-Mann and Ne'eman's prediction? On which ground did they believe in the existence of the new particle, and why did they think that this (supposed) new entity would have exactly the same characteristics as guessed by Gell-Mann and Ne'eman?

Here are the logical steps that, according to Bangu, underly the previous historical report[5]:

(P1) —*Each of the upper nine positions in the symmetry scheme has a physical interpretation.*

(H) —*Spin-$\frac{3}{2}$ baryons fit the symmetry scheme.*

(P2) —*The apex is formally/mathematically similar to the other nine positions. (It is similar in so far as it is, like them, an element of the scheme).*

(P3) —*The physical existence of a baryon having the predicted characteristics is not forbidden (can occur in nature).*

(RP) —*If Γ and Γ' are elements of the mathematical formalism describing a physical context, and Γ' is formally similar to Γ, then, if Γ has a physical referent, Γ' has a physical referent as well.*

(C) —*The apex position has a physical interpretation.* (*That is, the coordinates of this position describe a 10th spin-$\frac{3}{2}$ baryon.*)

≪ This line of reasoning—Bangu glosses—is supposed to answer the question asked by the experimentalist physicist ready to perform

[4] Actually, the story is not so simple. They could prove the existence of the Ω^- particle, along with its characteristics, *except* for its spin. Although this hyperon was discovered more than 40 years ago, a conclusive measurement of its spin has only recently been obtained by Aubert et al. (2006).

[5] See Bangu (2008, pp. 243–248).