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Article

Translations, Betrayals and Controversies in the Articulation of The Uncertainty Principle: Potentialities and Challenges of a Symmetrical History of Physics

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Abstract:

In this paper, we discuss the potentialities and challenges of historical approaches related to the Symmetrical Anthropology proposed by Bruno Latour and collaborators. To accomplish this goal, first, we provide a brief account about how Sociology and Anthropology of Science evolved, stressing how these different movements correlate with historiographical approaches. Second, we introduce the metaphysical scheme of Symmetrical Anthropology and discuss which characteristics a historical narrative should have to be consistent with this world vision. Third, we briefly describe the articulation of the Uncertainty Principle focusing on appropriating such characteristics. Based on this concrete historical account, we discuss the potentialities and challenges of this approach to History of Physics.

Keywords: Symmetrical Anthropology; Symmetrical Sociology; Actor-Network Theory; Symmetrical History; Science Studies

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Introduction

As any other utterance, historical narratives cannot be understood in isolation, since they are committed to different values, world views, and, in the case of the history of science, to different conceptions about nature of science. Hence, we may say that the different historical

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approaches always correlate with the various disciplines of their time (such as sociology, philosophy, anthropology, and sciences themselves). In this sense, the historiographic work consists of making this correlation explicit. As Videira (2007, 127) outlines, historiography should be a critical discourse that reveals, to the greatest extent, the epistemological, historical, political, and axiological roots on which historical discourses are built. In other words, historiography reveals the relation between the historical approach and different world views.

In the present work, we assess these relations, chiefly addressing that between History of Science (and, more specifically, History of Physics) and Sociology/Anthropology of Science. It is important to mention that there are many studies that propose a Sociology of Physics, which, of course, has important implications to History of Physics (Reyes Galindo 2011). Nonetheless, our main goal is to discuss the potentialities and the challenges of historical approaches that are, at some level, committed to the worldview that underlies what Bruno Latour (1993) calls Symmetrical Anthropology[4] – which has not been much explored in the field of History of Physics. We will call such historical approaches as Symmetrical History.

In order to follow Videira's recommendation, we briefly discuss different possibilities of History of Science according to its possible relations with Sociology and Anthropology of Science, following Latour's (1993) reasoning. In the sequence, we introduce Latour's world view (Latour 1993; 1999d; Latour et al. 2012; Latour 2016; 1988b; 1999e; 1988a; 2005), which claims to be rooted in a different metaphysical formulation when compared to previous sociological trends. Then, to make the potentialities and challenges of the approach clearer, we introduce a symmetrical history account of the articulation of the Uncertainty Principle.[5] And, finally, we present our final remarks.

The History of Symmetrical History

The presentation of historical narratives about science and physics had taken place through their whole development process, even though History of Science was only constituted as an autonomous discipline in the 20th century (Kragh 1987). In the beginning, the production of historical accounts had the purpose of contributing to the stabilization of science as a valid tradition in the pursue of truth, quarrelling with religion and philosophy (Videira 2007). The positivist doctrine proposed by Augusto Comte in the 19th century, for instance, suggested a linear conception of science progress, which unavoidably runs into a final point, which is the contemporary knowledge (Comte 1830).

According to Foucault (1979), this kind of history is concerned with the study of origins (*Ursprung*). In the origin resides the conception of the thing-in-itself (before any accident or distortion), the essence and the truth. In the Positivist History, to search for the origins is to search for the seed that ultimately and unavoidably will lead to our present knowledge; is to show the solid ground where contemporary conceptions stand upon.

So, this first era of historical approaches can be characterized by the narratives of scientists and epistemologists in defense of a specific conception of nature of science (Videira 2007; Alfonso-Goldfarb 1994). In this perspective, the progress of science is explained by some natural element, such as the discovery of truth or of an essence. We may

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[4] Latour uses this term in the essay *We have never been modern* (Latour 1993). As we will discuss, the worldview defended in this essay is consistent with further propositions of the author such as the Actor-Network Theory (Latour 2005).

[5] The articulation of the Uncertainty Principle, first presented in a paper written by Heisenberg in 1927, is addressed in several different works (Tanona 2004; Camilleri 2007; M. S. Longair 1984; Jammer 1966; Jijnasu 2016). Thus, we do not aim to claim any historical novelty, but rather the opposite, that is to explore the potentiality of looking to a known historical event with a new metaphysical worldview.

call these descriptions as "Epistemological History of Science".[6] They relate to Sociology and Anthropology by denying their role in characterizing scientific knowledge.

The structural changes that took place in the industrial revolution in the end of the 19th century corroborated the conception of science as the source of economic growth and social welfare, reinforcing the myth of linear progress (Auler and Delizoicov 2001). It seems to be a consensus, however, that confidence on science and on its capability of promoting social well-being was drastically called into question after the World War II (Lopes 2013), a scenario that allowed the rise of more critical accounts of the history of science, being pursued by historians, sociologists, and anthropologists (Lightman 2016). Latour (1993) describes this new era of sociological and anthropological accounts on science as disputed by two different movements: the critique and the deconstruction.[7]

Following Latour (1993), we may call "Critical History of Science" those historical accounts that explain science progress by mobilizing only elements from society (and no longer from nature). Shapin & Schaffer (1985) and Boris Hessen (2009)[8] exemplify this sort of historiography. Some premises of such descriptions were synthetized in the Strong Programme of Sociology (SPS) (Bloor 1991). Particularly, the program explores social causes for the "success" and "failures" of science instead of the asymmetrical description of the "Epistemological History", in which natural causes explain the success and social causes explain the failures.[9] As Latour (1993) points out, however, the SPS deconstructs nature as the source of truth, but it still reifies social structures. If the natural essences are not objective and intrinsically real for the SPS, the social structures are.[10] In this sense, Latour (1993) claims that it is not possible to say that SPS is fully symmetrical.

On the other hand, the "deconstruction movement" and consequently what we may call "Deconstructive History" went further, dissolving not only nature but also society – reducing reality to games of language and power (Latour 1993). Although Derrida (1997) is often mentioned as the leading figure of deconstructivism, a clear example of "Deconstructive History" can be found in Foucault's (1979a; 1979b) discussion on the relation between truth and power and his proposition of genealogical studies. More specifically, Foucault (1979a) proposes genealogy as a study opposed to the search of origins (*Ursprung*). Instead of adopting the teleological perspective of the positivist history – the supra-historic standpoint from which is possible to analyze history, the genealogist is committed to highlighting the singularities and specificities of each event. Thus, genealogy is devoted to the accidents and not the essences.

Therefore, genealogists do not search for the *Ursprung* (the thing-in-itself, the essence and the truth): what they search for is the *Herkunfut* (provenance) and the *Entestehung*

[6] Bruno Latour (1993) discusses Bachelard's description of science to characterize epistemology as the discipline that explains scientific knowledge using natural elements only. Although proposed in a different period, Lakatos' (1978) rational reconstruction also could be included in this sort of historiography.

[7] Videira (2007) speaks about a post-positivist period in History of Science – from 1945 to 1970 – in which Thomas Kuhn's *Structure of Scientific Revolutions* (Kuhn 1996) plays an important role – and a post-modernist period, from 1970 on. It is possible to make a parallel between the post-positivist history and what Latour calls "critique" and post-modernist history and "deconstruction", although these categories do not fit completely.

[8] Originally delivered in 1931 at the Second International Congress of the History of Science in London, it is prior to the 1945 turning point of History of Science (Videira 2007). Despite of that, its proposal embodies the spirit of what Latour calls critique.

[9] For instance, the "Epistemological History" explains geocentrism by saying that it was grounded in religious tradition while heliocentrism was allowed by the discovery of the true system. In other hand, "Critical History" would explain both movements through social causes, as the adoption of a specific religious view.

[10] Latour's critiques on SSP were challenged by Bloor (1999) and then, reaffirmed by Latour (1999b).

(emergence). While *Herkunft* is associated to singularities of events, as well as accidents and distortions, *Entestehung* is associated to the dispute, conflict, and shock of forces. Emergence is only produced in a determined state of powers. In this sense, genealogy does not provide any certainty, neither it shows us that science was created on a solid foundation – on the contrary, it stresses the lack of any foundations, rationality or stability as the characteristic of events, which always are singular.

In summary, Epistemological History describes science as something independent of society. On the other hand, Critical History ascribes to social structures the source of scientific progress (its successes and failures) and Deconstructive History gives up any attempt to provide solid ground for scientific endeavors. Instead of deciding which claim is true, Latour (2016) proposes to take the controversy of the different approaches as the object of study and to explain how this was possible in the first place. The objective of Latour's (2016) historical accounts is to show how something that was politically disputed, that depended on the social affairs and that was constructed upon accidents and mistakes, in the end rises as objective and natural.

In order to do so, it is not possible to be committed with the metaphysical perspective of the previous historiographical trends (Latour 1999d). It is necessary to adopt another posture about the relation between nature and society – what can be called fully symmetrical perspective (Latour 1993). This new metaphysical perspective was built up by Latour and collaborators through decades and is still object of philosophical construction (Harman 2009). It is chiefly grounded in Sartres's Existentialism (Sartre 2007), Callon's Sociology of Translation (Callon 1984), Whitehead's Philosophy of Propositions (Whitehead 1978) and Tarde's Monadology (Tarde 2007).

Sociology of Translation, Philosophy of Propositions and Actor-Network Theory: A Monadological Perspective to Describe History of Science Symmetrically

According to Latour (1993), the modernist period is an attempt to forge an absolute separation between nature and society, as what we observe in Kant's (2005) philosophy. The "Epistemology" is firmly grounded in this ontological scheme. Despite of that, when we look to laboratories and historical primary sources, what we find is the process of intense hybridization of natural and social elements in what Latour (1993) calls quasi-objects (or hybrids).

On the other hand, the Critique dissolves nature while sustaining society as an ontological pole, and Deconstruction dissolves everything. As we have pointed out, however, although the Positivist History seems not to resist to an accurate and deep analysis of the primary sources, it seems that scientific knowledge at some point resists to human volition and subjectivity. Otherwise, in the middle of a pandemic, should we consider scientific orientations only as an effect of discourse?

In order to provide an alternative description of scientific knowledge and progress, one that is epistemic but not only epistemic, sociological but not only sociological, and discursive but not only discursive, Latour starts from Sartre's (2007) existentialism, according to which the rejection of the conception of God in contemporary philosophy implies that human nature has no essence. Humans were not created to be something, so they do not have a pre-existing essence – they produce and stabilize their essence along their lives.

What Latour (1993) proposes with Symmetrical Anthropology is to extend Sartre's conception to all non-humans, to all quasi-objects: their essence is not something pre-existing too, but something to be stabilized along time. In this sense, the scientific practice does not discover nature, but it creates nature and makes it stable. There is a particularly important but subtle element in this perspective: Symmetrical Anthropology is also non-essentialist as Deconstruction, but it emphasizes the capacity that different actors[11] have of creating and stabilizing essences. In this sense, its focus is on construction and association and not on destruction.

This conception has direct impact on how history is told: one should not look for objective pre-existing beings that meet with each other. On the other hand, what one seeks is the articulation of actors, whose essence is not objective and immutable. One aims to explain how these new articulations change their essence and create new actors. In the end, nature and society are created and stabilized by the practices of the actors and not the contrary (this is the key feature of Actor-Network Theory). One way of describing such articulations is through the terminology of the Sociology of Translation, which is based on three principles: agnosticism, generalized symmetry, and free association (the abandonment of all a priori distinctions between the natural and the social) (Callon 1984, 196).

The generalized symmetry and the free association principles lead us to propose that humans and non-humans must share agency along history (Latour 1999a). In this sense, non-humans are not material objects waiting to be used by humans, as they also change the course of human actions. When scientists speak, they are proposing something that was constructed in the articulation of humans and non-humans. Every time this happens, the result is a process of "translation", which is never the simple combination of the original programs of action, but rather something new: "In place of a rigid opposition between context and content, chains of translation refer to the work through which actors modify, displace, and translate their various and contradictory interests" (Latour 1999d, 311).

In the process of translations, the scientist, in particular, may assume the role of spokesman – representing all non-humans (which cannot speak) in the same way political representatives speak in the name of an assembly of humans that would not be listened if they were to speak all at the same time (Latour 1993). This translation always involves uncertainties, and, sometimes, the spokesman may betray the group (Callon 1984).

This non-essentialist and symmetrical perspective was adopted by Latour (1999c) to organize a historical account on Pasteur's work on fermentation. In this case, Pasteur's work resulted in the existence of a new actant – the yeast. This process of coming into existence by the mediation and translation is called by Latour as articulation, which derives from Whitehead's Philosophy of Proposition (Whitehead 1978). According to this perspective, each actor may be recognized as a proposition, which only exists by the articulation of other propositions. It is important to note, however, that when Pasteur mobilizes equipment, theories and samples in his laboratory trials, the microbes become articulated by all these propositions and they become independent of Pasteur himself (it is not subjective anymore). That is why Epistemology, Critique and Deconstruction are at some point right: all of them emphasize different dimensions of the same process.

Therefore, Symmetrical Anthropology (and, as a consequence, what we call Symmetrical History) attempts to explain how the whole collective of humans and non-humans come into existence and how they change over time. All actors (humans and non-humans) have agency, they transform reality and impact other actors' agency as well as they are transformed and have their agency impacted by other actors. This metaphysical perspective, however, is not new in Sociology (Latour et al. 2012; Latour 2001). Gabriel Tarde (1843-1904) proposed a monadological sociology, defending that the use of the concept of monad (minimum element, whose existence is actually sustained by the relations with other monads) was crucial to sociology (Tarde 2007). According to Tarde (2007), science does not

[11] Actor is defined in the following sense: "Instead of starting with entities that are already components of the world, science studies focus on the complex and controversial nature of what it is for an actor to come into existence. The key is to define the actor by what it does-its performances under laboratory trials" (Latour 1999d, 303).

owe its progress to the adoption of a positivist perspective, but to the search of monads – such as atoms, molecules and cells.

A Symmetrical History of Physics: Methodological Considerations

From the Symmetrical Anthropology and its metaphysical scheme, we propose six characteristics to Symmetrical History. These characteristics should not be understood as rules, but a translation of the metaphysical perspective. It is very important to highlight that for an account to be a Symmetrical History it does not have to use Latour's concepts explicitly but only to be consistent with the metaphysical perspective (Latour 2005). In other words, it does not need to speak about quasi-objects, actors, and so on. Certainly, if during the process the necessity of mobilizing a specific concept rises, it is possible to use it, yet it is not necessary. Accordingly, Symmetrical History is the one that shows the following characteristics:

a) **The history moves toward the stabilization of nature and society.** Symmetrical History reveals how elements of nature and social structures were articulated and stabilized after a controversy. We may describe the provenance and emergence – which reveal the singularities of the event. However, we must highlight what makes nature and society stable.

b) **Non-humans have agency:** Instead of telling a history in which humans use objects to make history, Symmetrical History observes how humans and non-humans articulate, mediate, and translate each other. Of course, the scientist plays the role of spokesman, but again their will is affected by non-humans' agency at some point.

c) **Actors do not exist independently – they are the articulation of other actors.** Instead of considering "reality" a binary property, Symmetrical History acknowledges reality as a continuous spectrum. An actant exists according to the number and stability of associations of its network. In this sense, Symmetrical History is non-essentialist. In Symmetrical History, one shows the work of the scientist to mobilize elements to make a new actor real.

d) **Knowledge and Belief are symmetrical:** All statements are valid in a specific network, in a specific set of propositions – what Latour calls space-time envelope (Latour 1999d).

e) **It is possible to hierarchize propositions:** Although there is not any essential difference between knowledge and belief, in a certain spacetime envelope, it is possible to compare the networks mobilized by different actors. In this sense, it is possible to hierarchize propositions. There are propositions that exist more than others, and as a consequence some statements are truer than others.

f) **Interior and exterior of science are mixed:** Instead of separating the social from the natural, Symmetrical History deals with collective of humans and non-humans. Thus, it is not possible to separate interior from exterior of science, ontology from epistemology and epistemology from politics (Latour 1999d). This does not mean that all these aspects must be present all the time, but rather that they may be (Latour 2005).

g) **Actors must speak:** Instead of projecting a priori categories onto the history or aiming to find the "real history", one should focus on listening and reporting the actor's own narratives. In this sense, the symmetrical history is always based on narratives of the own protagonists, with all subjectivities and controversies that this can bring about. We do not expect to mirror "historic reality", but to articulate what Latour (2005) calls a risky account. By bringing more points of view into the account, one makes it more stable.

The six characteristics that we propose for Symmetrical History may also be found in two of Latour's historical studies on Physics (Latour 1988a; 1999f). When we think about Physics, however, some specificities that were not addresses by Latour may appear. Specially, there are theoretical works on Physics that do not deal with any laboratory experiment, which is a key element of Latour's description. In this case, a different sort of actor seems to play an important role: the "mathematical actor". Mathematical symbols in theoretical Physics may be considered actors in the same way as laboratory equipment is. And mathematical manipulations should be like laboratory experiment. In this sense, we claim that mathematical symbols should be treated as any other non-human for Symmetrical History. Although Latour does not discuss this issue, the reader can find a wide literature about the interplay between Physics and Mathematics (Ferreira and Silva 2020; Lützen 2013; Paty 2003).

In the next section, we will propose a symmetrical discussion on the articulation of the Uncertainty Principle, chiefly discussing Heisenberg's (1927) paper.[12] We intend to discuss how it was possible to pass from a deterministic world to a world of indeterminacies in 1927.[13] In order to achieve such a goal, we will try to answer the following questions: what were the associations necessary for the Uncertainty Principle to come into existence? What were the translations? Which were the variations of meaning and agency? Were there betrayals? What was Heisenberg's program of action? Has he succeeded or failed?

The Articulation of the Uncertainty Principle – translations and betrayals[14]

Emergence (*Entestehung*) of the Uncertainty Principle

The beginning of the 20th century was colored by the intense proliferation of new actants (such as the quantum, the atom, the wave function, and so on) and of new principles legislating the behavior of this new "nature", such as the Ehrenfest's Adiabatic Principle and

[12] We will follow the English translation (Heisenberg 1983a). We also address a comment made by Heisenberg (1983b) in 1967. It is important to stress that it is far known that, after World War II, Heisenberg aimed to present himself in a nice picture (Howard 2004). Thus, this narrative should be considered a risky account – in which the interests and conceptions of Heisenberg (the spokesman) are already hybridized with the primary sources. If we were interested about discovering the consistencies of Heisenberg's narrative, we should search for other spokesmen and to confront their accounts – which could be object of another study.

[13] There is a distinction between uncertainty and indeterminacy. The first refers to fluctuations associated to a measurement while the second refers to something that is intrinsic in nature (Jammer 1966). As we will discuss, Heisenberg's 'Uncertainty Principle' led to an indeterminate worldview.

[14] As we will discuss in the final remarks, along the text we overemphasized some categories to highlight the potentialities and challenges of this historiographic trend. In a usual historic presentation these categories would not need to be discussed explicitly.

Bohr's Correspondence Principle (Jammer 1966). Although many movements and actors can be mentioned, two special programs of action are important to be highlighted.

Leaded by Albert Einstein, the first one promoted the study of radiation from the perspective of thermodynamics and Statistical Mechanics (Klein 1967), leading to the articulation of a corpuscular radiation in 1905 and of a dual radiation in 1909, based on a strong realist perspective and a deep sense of unification.

In another direction, we may observe the studies about the structure of matter and, more specifically, the development of atomic models. In this scenario, Niels Bohr may be mentioned as one of the exponents (Kragh 2012). The physicist developed another culture of approaching Physics, as he had a different philosophical background when compared to Einstein. He was much influenced by William James' pragmatism and by Harald Høffding's studies on Søren Kierkegaard (Jammer 1966). Many of his ideas were directed toward the possibility of blurring the boundaries between the subject and the object – the distinct and non-accessible Kant's ontological poles –, a concept that plays an important role in the Copenhagen Interpretation (Heisenberg 1958).

The development of Bohr's 'astronomical' model for the atom motivated a revival of the interest for mathematical methods used in Astronomy (such as in the Celestial Mechanics written by Laplace in the beginning of the 19th century), which could be used in the description of matter.

In 1925, Werner Heisenberg produced a paper in which he adopted the mathematical formalism coming from the studies on celestial mechanics to inaugurate what would become Quantum Mechanics. Heisenberg was committed not only to a determined way of practicing Physics, but also to a specific Philosophy of Physics, firmly grounded in the positivist doctrine, as it can be seen from the abstract of his *Umdeutung* paper: "The present paper seeks to establish a basis for theoretical quantum mechanics founded exclusively upon relationships between quantities which in principle are observable" (Heisenberg 1967, 261).

The development of Heisenberg's program in the subsequent years by Heisenberg himself, Born, Dirac, Jordan and Pauli would lead to Matrix Mechanics and to Transformation Theory. Furthermore, after 1924, Heisenberg started an intense collaboration with Niels Bohr, and in 1926 he became a lecturer in Copenhagen, at the same time Dirac and Jordan were also there. Matrix Mechanics, thus, can be considered the translation of the Mechanics of the Atom, atomic spectra and Niels Bohr's original program. The formulation is grounded in the discontinuity of atomic processes, matrix formalism, pragmatism, existentialism, and positivism.

However, the stabilization of this program would have been deeply impacted by the rise of a competitor, not only rooted in a different philosophy, but grounded in a different mathematical formalism and supported by other set of physical data. To be more precise, Erwin Schrödinger had long studied Statistical Mechanics, and for many years was searching a description of quantum phenomena that could be compatible not only with Special Relativity but also with General Relativity (Joas and Lehner 2009). Schrödinger, as Einstein, was committed to a realistic perspective and, in the year of 1926, proposed Wave Mechanics, in which not only electromagnetic radiation was described as continuous waves but electrons too. In this way, Schrödinger's program was based on continuity. It also described atomic spectra, dealt only with differential equations (and not matrixes) and was grounded in realism.

In 1925, Werner Heisenberg attended one of Schrodinger's lectures in Munich (Heisenberg 1983b), when he presented his undulatory interpretation of Quantum Mechanics. Heisenberg was disturbed by Schrödinger opposition to quantum jumps and discontinuities, but nobody seemed to agree with his objections – on the contrary, Schrödinger's interpretation seemed to just gain popularity among the theoretical physicists:[15] it offered a clear picture of what was happening in the quantum level and it used mathematical formalism with which physicists were acquainted (differential equations).

Not much later, Niels Bohr invited Schrödinger to go to Copenhagen to debate the interpretation of Quantum Theory. After long and exhaustive debates (which, according to Heisenberg (1983b) led Schrödinger to be physically sick), Schrödinger's continuous description and Bohr's quantum jumps could not be reconciled. After Schrodinger had left Copenhagen, the researchers of Bohr Institute centered their attention towards the problem of formalism and interpretation of Quantum Mechanics, analyzing the many paradoxes that the different interpretations could produce.

This was the scenario that allowed the "emergence" of the Uncertainty Principle, where there is the confrontation between two worldviews, with their own philosophies, mathematical structures, conceptual bases, phenomena and scientists. Each one of the opposite networks are in a struggle to stabilize itself and destabilize the other. This conflict is summarized in the introduction of Heisenberg's 1927 paper:

> The physical interpretation of quantum mechanics is still full of internal discrepancies, which show themselves in arguments about continuity versus discontinuity and particle versus wave. Already from this circumstance one might conclude that no interpretation of quantum mechanics is possible which uses ordinary kinematical and mechanical concepts (Heisenberg 1983a, 62).

Heisenberg as a Spokesman

In 1927, Niels Bohr was still not convinced about how to solve such controversy – and it was only when he left Copenhagen on vacation that Heisenberg decided to take the lead and to assume the role of spokesman, proposing his own interpretation (Heisenberg 1983b). In this sense, we may understand Heisenberg's paper as the defense of the whole program that started in 1925.

Heisenberg had a cause to defend and an alternative narrative to deconstruct. Like a lawyer in the tribune, his objective was to defend a claim and make it plausible. To do so, he had to expose the claim, show proofs, find allies and witnesses, and disqualify the opposite interpretation. He had to convince that he had the most suitable way to describe and interpret Quantum kinematics and dynamics.

Some elements of his claim are explicitly expressed on the paper's abstract, others are distributed throughout the paper and are defended only implicitly. In order to make the argument clearer, we synthetize Heisenberg's claim in five utterances. Along our presentation, we will show how Heisenberg defend all of them:

a) **Quantum objects are particles.** Waves should not play any role in Quantum Mechanics.

b) **One can only speak about observable quantities.** Discontinuity, thus, is a key feature of quantum reality.

c) **Dirac-Jordan theory is the correct formalism to mathematically describe quantum mechanics** (Heisenberg 1983a, 62). Schrödinger's formalism is therefore unnecessary.

[15] In 1927, for instance, Heisenberg refers to Schrödinger's interpretation as "popular" (Heisenberg 1983a).

d) **Canonically conjugate quantities can be determined simultaneously only with a characteristic indeterminacy** (Heisenberg 1983a, 62). Although the term used is indeterminacy, Heisenberg understands that the relation of uncertainty is caused by the measurement equipment.

e) **This indeterminacy is the real basis for the occurrence of statistical relations in quantum mechanics** (Heisenberg 1983a, 62). Since all we can speak about is what we measure, to say that there is uncertainty in the measure is equivalent to say that there is indeterminacy. This indeterminacy is the source of all statistical relations, which are described by the formalism as a sort of error propagation.

To convince the scientific community about his claim, Heisenberg needs to mobilize a set of witnesses and allies.

Gedanken Laboratory Witnesses

To exemplify what he meant, Heisenberg proposed throughout the paper different *Gedanken* experiments involving the simultaneous measuring of non-commutable observables such as position and momentum, time and energy and action and angle variables. In each case, Heisenberg provided rough phenomenological descriptions and found a relation between the uncertainty associated to each pair of variables. For the case of the relation between momentum and position, he discussed the case of an electron observed in a gamma-ray microscope. For the case of the relation between time and energy, he discussed the split of a beam of atoms in a Stern-Gerlach experiment. Finally, for the case of the relation between action and angle variable, he discussed the Franck-Hertz experiment.

In each *Gedanken* experiment involving non-commutable variables by which Heisenberg found an uncertainty relation, the experiment became a witness of his claim. Let us see how he presented this sort of reasoning:

> At the instant when the position is determined – therefore, at the moment when the photon is scattered by the electron – the electron undergoes a discontinuous change in momentum. This change is the grater the smaller the wavelength of the light employed – that is, the more exact the determination of the position. At the instant at which the position of the electron is known, its momentum therefore can be known up to magnitudes which correspond to that discontinuous change. Thus, the more precisely the position is determined, the less precisely the momentum is known, and conversely. In this circumstance, we see a direct physical interpretation of the equation $\boldsymbol{pq} - \boldsymbol{qp} = i\hbar$. Let q_1 be the precision with which the value q is know (q_1 is, say, the mean error of q), therefore here the wavelength of the light. Let p_1 be the precision with which the value p is determinable; that is, here, the discontinuous change of p in the Compton effect. Then, according to the elementary laws of Compton effect p_1 and q_1 stand in the relation $p_1 q_1 \sim h$. (Heisenberg 1983a, 64)

Since the microscope cannot speak, Heisenberg spoke for it and used its “speech” in his defense. We will discuss in more detail some aspects of this translation in the next sections. At this point, we just want to highlight the role that non-humans play in the articulation of Heisenberg’s proposition.

Mathematical Witnesses

The non-human witnesses of the *Gedanken* laboratory truly corroborated the case and participated in the articulation of Heisenberg's proposition. However, Heisenberg's presentation of such examples was always rough, and, in a sense, they give the impression that if, for instance, another experiment was chosen to determine position and momentum, it would be possible to overcome the indeterminacy limits. To provide a universal principle, it would be necessary to provide more than "laboratory trials"; it was necessary to provide something that would be more stable than the choice of a laboratory equipment. He needed a "mathematical trial". When one uses the mathematical formalism to represent a quantity, one represents it regardless of the equipment used. Thus, all Heisenberg must do is to speak in the name of mathematics.

To do so, Heisenberg proposed that when we represent a particle using Jordan's formalism with a Gaussian function, the standard deviation should be pragmatically interpreted as the standard deviation (or mean error) of a measurement. This interpretation, however, is not something that is expressed in the equation, but added by the spokesman when he speaks in the name of the equations. By proposing this interpretation, Heisenberg wrote the gaussian function representing a particle in the q-space (position-space). Multiplying the function by its complex conjugate (what, nowadays, we recall as the probability density function), he obtained the expression

$$S\bar{S}'\ proportional\ to\ \exp\left[-\frac{(q-q')^2}{q_1^2}\right] \tag{1}$$

Also, using Dirac-Jordan Theory, it is possible to transform S from q-space to p-space and, again, compute the product with its complex conjugate. Heisenberg found that

$$S\bar{S}'\ proportional\ to\ \exp\left[-\frac{(p-p')^2}{p_1^2}\right] \tag{2}$$

Where p_1 and q_1 are related through

$$p_1 q_1 = \hbar \tag{3}$$

It should be stressed that Heisenberg proposed an equality (and not an inequality, like it is expressed nowadays).[16] Despite of that, in the same paper, Heisenberg showed that the product between the uncertainties can be larger than $\hbar$, but because of his pragmatic interpretation he considered that the equality is the only right expression. According to Heisenberg, the wave packet described in t=0 establishes a region where the particle can be found around a mean value with some precision. After some time, the inaccuracy increases in the position of the particle, since the original indeterminacy is propagated, making the wave packet broadened. However, after a second measurement, the position of the particle turns to be determined in a specific region whose length is equal to the initial one (and which is determined by the precision of the equipment used). In other terms, the measurement reduces the extension of the wave packet – what nowadays could be called the collapse of the wave function.

[16] According to what is known today, the equality only holds for gaussian packages at a specific time. For other wave packet shapes and as time runs, the product becomes larger than $\hbar/2$.

Furthermore, Heisenberg computed the extension of the wave packet after a period t, and he showed that it was bigger than the original one. In this sense, Heisenberg had the chance to rewrite his uncertainty equation as an inequality ($q_1 . p_1 \geq \frac{\hbar}{2}$), but as he interpreted the relation as something that spoke about the measurement situation, where the wave packet was reduced to the original length, he sustained the relation as an equality.

Philosophical Argumentation

To make the case plausible, Heisenberg must assign the phenomenological outputs to the mathematical formalism and provide a consistent worldview. This worldview is articulated by three philosophical standpoints.

First, Heisenberg addressed the problem of how concepts coming from classical mechanics can be used in the atomic dimension. Influenced by an argument that often appears in Bohr's argumentation (Heisenberg 1996), Heisenberg assumed that we cannot describe reality with concepts that we have not used classically, since our way of describing reality (our conception of space and time, for instance) are *a priori* conditions of knowledge itself, as it is expressed in the Kantian philosophy (Kant 2005). Despite of not being able to provide new concepts to speak about reality, it does not mean that the *a priori* judgements are absolute and universal. The concepts that we use in the classical world can only be used in Quantum Mechanics considering that there is always some uncertainty related to the measurement of two conjugate quantities. In this sense, Heisenberg advocates for a revision of Kantism.

Furthermore, it is possible to recognize some influence of Kierkegaard in Heisenberg's argument. Heisenberg claims that it is not possible to isolate a quantum object:

> In order to be able to follow the quantum-mechanical behavior of any object one has to know the mass of this object and its interaction with any fields and other objects. Only can then the Hamiltonian function be written down for the quantum mechanical system (...) About the "gestalt" (construction) of the object any further assumption is unnecessary; one most usefully employs the word "Gestalt" to designate the totality of these interactions. (Heisenberg 1983a, 64)

The "Gestalt" construction that Heisenberg described directly confronts the Kantian scheme in which there are object in themselves (independent of their surroundings) as it was explained by Heisenberg (1996) himself – and it holds a parallel with Kierkegaard's philosophy. Moreover, this Gestalt worldview was hybridized with positivist and pragmatic postures. In order to call attention to the depth of what he was about to propose, Heisenberg, again, makes a parallel with the Special Theory of Relativity, stressing that to determine a position means to determine the experiment with which is possible to determine position:

> When one wants to be clear about what is to be understood by the words "position of the object", for example of the electron (relative to a given frame of reference), then one must specify definite experiments with whose help one plans to measure the position of the electron; otherwise this word has no meaning. (Heisenberg 1983a, 64)

Finally, he mobilized a positivist interpretation in its highest expression in the following excerpt: "I believe that one can fruitfully formulate the origin of the classical "orbit" in this way: the "orbit" comes into being only when we observe it" (Heisenberg 1983a, 73).

Attacks against Schrödinger's Wave Mechanics

Besides defending his own claim, Heisenberg attacked Schrödinger's Mechanics three times throughout the paper. In the first one, he mentioned that Dirac's formulation is the truly invariant formalism, which was an important feature if one thinks in terms of the development of a relativistic quantum mechanics. Second, Heisenberg discussed the relation between Micro and Macromechanics (this is the title of one of Schrödinger's papers), opposing to Schrödinger's previous discussions: "The transition from micro- to macromechanics has already been treated by Schrödinger, but I do not believe that Schrödinger's considerations get to the heart of the problem"(Heisenberg 1983a, 73). Finally, in the third attack, Heisenberg stressed his disagreement with Schrödinger:

> Certainly, one cannot overestimate the value of the mathematical (and to that extent physical) mastery of the quantum-mechanical laws that Schrödinger's theory has made possible. However, as regards questions of physical interpretation and principle, the popular view of wave mechanics, as I see it, has actually deflected us from exactly those roads which were pointed out by the papers of Einstein and de Broglie on the one hand and by the papers of Bohr and by quantum mechanics on the other hand. (Heisenberg 1983a, 82)

Heisenberg's Final Defense: A New Nature

The problem that Heisenberg addressed to close his defense is how it is possible to link the statistical nature of Quantum Mechanics with the existence of conservation of physical quantities. Heisenberg's answer is that the problem is not in the logical structure of causality, but in its premises, i.e, it is never possible to determine precisely the initial state of a system, so we cannot predict precisely its subsequent states:

> But what is wrong in the sharp formulation of the law of causality, "When we know the present precisely, we can predict the future," is not the conclusion but the assumption. Even in principle we cannot know the present in all detail. For that reason, everything observed is a selection from a plenitude of possibilities and a limitation on what is possible in the future. (Heisenberg 1983a, 83)

In this sense, it seems that Quantum Mechanics suggests that there is a real independent world where causality holds. However, this world is inaccessible to us because every measurement perturbs the original system. In this sense, all we have access to, all we can observe is not contemplated by this "causal world" and is subject of uncertainty relations. Taking the positivist position seriously, all we can talk about is the measurement results, and thus causality finally fails:

> As the statistical character of quantum theory is so closely linked to the inexactness of all perceptions, one might be led to the presumption that behind the perceived statistical world there still hides a "real" world in which causality holds. But such speculations seem to us, to say it explicitly, fruitless and senseless. Physics ought to describe only the correlation of observations. One can express the true state of affairs better in this way: Because all experiments are subject to the laws of quantum mechanics, and therefore to equation (1), it follows that quantum mechanics establishes the final failure of causality. (Heisenberg 1983a, 83)

The indeterminate nature was born.

Translations and Betrayals

We have passed through the main points of Heisenberg's defense: his claim, the mobilization of *gedanken* laboratory experiments, the mobilization of Dirac-Jordan mathematical formalism, the use of pragmatism, existentialism and positivism to interpret all the articulation and his final defense. The combination of all these elements corresponds to a translation that is conducted by Heisenberg, the spokesman.

Nevertheless, in this process at least two characters were betrayed. The first was Bohr, who did not commit to the full rejection of wave description of quantum phenomenon. As we will discuss on the next section, when Bohr read the first version of the paper, already approved but not published, he convinced Heisenberg to add a note mentioning that the wave description of radiation was used in the analysis of the gamma ray microscope and that it was an essential part of Heisenberg's description! Actually, the defense of both pictures – corpuscular and undulatory – was performed by Bohr in 1928 in his proposition of the Complementarity Principle (Bohr 1928). In this sense, Heisenberg's intention of rising as the spokesman of the Copenhagen program was frustrated by Bohr's opposition to a purely corpuscular description.

Moreover, a central aspect of Heisenberg's proposition is the derivation of the uncertainty relation from the Dirac-Jordan's formalism. Despite of using their formalism, Heisenberg denied Jordan's interpretation of Quantum Mechanics. In 1927, Jordan had already proposed a probabilistic interpretation, which was not associated simply to the measurement process (Longair 2013). Heisenberg thus mobilized Jordan's formalism but betrayed his interpretation:

> Of course, we would also like to be able to derive, if possible, the quantitative laws of quantum mechanics directly from the physical foundations—that is, essentially, from relation (1). On this account Jordan has sought to interpret the equation $S(q,q'') = \int S(q,q')S(q',q")dq'$, as a probability relation. However, we cannot accept this interpretation (§2). We believe, rather, that for the time being the quantitative laws can be derived out of the physical foundations only by use of the principle of maximum simplicity. (Heisenberg 1983a, 82)

These two betrayals had concrete consequences to Heisenberg's program.

Provenance (*Herkunfut*) of the Uncertainty Principle

In the process of mobilizing allies, sometimes Heisenberg presented contradictory statements or, at least, not very rigorous reasonings, as pointed by Bohr. Some of them were addressed in the note added during the editing process. Let us examine some of the "unstable points" of the microscope *Gedanken* experiment:

i) q_1 is called the mean error of q. The calculation of this parameter is based on the wave theory of light (it is caused by diffraction), while p_1 is computed with a corpuscular theory (it is caused by the Compton Effect), which makes Heisenberg sustains both pictures at the same time, the opposite of what we claimed to do, as pointed out by Bohr

ii) p_1 is not a mean error, but the maximum variance of momentum. So, while q_1 is an error, p_1 is a disturbance (Jijnasu 2016).

iii) Heisenberg did not consider the problem of the real microscope and ignored concrete factors such as the objective diameter.

iv) Heisenberg did not show how the indeterminacy came from the commutator relation; he just attached them. Throughout the paper, Heisenberg claims that the commutator was the origin of the uncertainty relations, but he did not prove it.

v) Heisenberg stressed the necessity of expressing how a physical quantity is measured. In the *Gedanken* experiment, he described how q is measured and what q_1 means in the experiment: there is not any concern to measure p and to empirically define p_1.

Besides these internal instabilities, in the case of the uncertainty principle for time and energy, also there are some contradictions that would be pointed out by other scientists:

a) Heisenberg claimed that the uncertainty principle for time and energy came from the commutation relation between these two quantities. However, in the subsequent years, it was shown that it is not possible to propose an operator of time that it is self-adjoint through all the spectrum (Busch 2008).

b) In the Stern-Gerlach experiment, time is treated as the time necessary to perform a measurement. However, Heisenberg also uses time as the interval of a transition:

> the time transitions or 'quantum jumps' must be as concrete and determinable by measurements as, say, energies in stationary states. The spread within such an instant is specifiable is given according to equation (2) by $\frac{h}{\Delta E}$, if ΔE designates the change of energy in the quantum jump. (Heisenberg 1983a, 76)

While the first is an external measurement of time, the second is an intrinsic parameter (Busch 2008). Finally, Heisenberg's derivation using Dirac-Jordan's theory used a gaussian-wave packet arbitrarily, without any justification. Despite of that, he claimed that the uncertainty relation is valid to all conjugate variables.

Stabilizing Nature

Heisenberg's analysis of the gamma microscope contradicted his own claim. He also forgot many important features of the experiment. He claimed to speak about measurement errors, but he referred to position error and to momentum perturbation (this one, only estimated and not measured). He changed the concept of uncertainty along the paper, sometimes referring simply to an interval (as in the case of time). He claimed that the uncertainty relation came from the commutation relation, but he did not show it. He assumed a commutation relation for time and energy that cannot be written uncritically. His derivation was for a specific case and he claimed it to be universal. We have all these reasons to agree with Foucault that in the base of science there is only error and accident.

Despite of that, nature became somehow indeterminate after 1927. Somehow an Uncertainty Principle emerged and remains alive until today. The way we can explain that is by recognizing that the uncertainty relation was not only articulated by Heisenberg. He was the spokesman. But the proposition was also articulated by non-humans. And non-humans have their own agency. In the case of the uncertainty relation, the equations mobilized by Heisenberg turned out to speak what Heisenberg could not speak himself.

Heisenberg's interpretation, his main claim and defense, the one based on the betrayal of Bohr's conception and Jordan's interpretation, was not successful at all. Today, we learn Quantum Mechanics through Schrödinger's Equation and not Dirac-Jordan's formalism. And we speak about probability waves and not error propagation. However, the mathematical structure of the uncertainty principle (without Heisenberg's interpretation) was more solid than his intention, and its association resisted.

Following Jammer's (1966) reconstruction, just after Heisenberg published the paper, in the same year, Kennard (1927) has shown that the Gaussian case was the minimum bound to the indeterminacy relation. Also, in 1928, Hermann Weyl (1950) demonstrated the Uncertainty relation as an inequality (which is valid for gaussian and non-gaussian packages). In the same year, C. G. Darwin (1928) has pointed out that the transformation between the position and momentum representations can be understood in terms of a Fourier transform, Ruark (1928) called the uncertainty relation as The Uncertainty Principle, and Kennard (1928) computed the uncertainty in position and momentum for an electron passing through a shutter, showing that it corresponds to the Fourier resolution of a train of waves passing through the same shutter. The mathematical proof that the uncertainty relation holds to all canonical conjugate variables only came in 1929 (Robertson 1929). After Robertson's publication, Schrödinger (1930), whose interpretation of Quantum Physics was competing with Heisenberg's conception, found a new and more general expression for the Uncertainty Principle.

So, what was successful in Heisenberg's proposition was not his interpretation, his claim, but the objective mathematical structure that was independent of him, and that resisted to his interpretation. This was the stable association that allowed the Principle of Uncertainty to survive along history. An important question is why, then, this mathematical association was so stable? If we take Gabriel Tarde's claim seriously, that science progresses every time it adopts a monadological perspective, the success of Heisenberg was to introduce the monad of determinacy, what can be thought – as Heisenberg himself mentions – the monad of "volume in the phase space" (Heisenberg 1983a, 65)[17]. As Tarde claims, this monad ought to be an essential part of reality, dependent- of course- of other monads- but still stable enough to resist Heisenberg's translations and betrayals.

Final Remarks

We discussed possible characteristics of a historical account that relate with Symmetrical Anthropology. We understand that, for a history to be symmetrical, it does not have necessarily to use specific concepts, but it must agree with the presented metaphysical scheme. We exemplified that with the discussion on the articulation of Uncertainty Principle. The main challenge to produce such a narrative was to decide about when to explicitly use the concepts of Symmetrical Anthropology. Not using them at all would make difficult for the reader to connect the narrative with the theoretical discussion; using them too much could make it obscure. So, there is an equilibrium point that is not easy to achieve and that must be pursued in every narrative.

On the other hand, our narrative allowed us to speak about theoretical physics without using a sectarian language – we reframed Heisenberg's work as the work of a lawyer in the tribune (characteristic "f"). We discussed the necessity of mobilizing different actors for the

[17] According to the intrinsic interpretation of the Uncertainty Principle (Jijnasu 2016) one may think that, differently of Classical Mechanics, according to which a particle may occupy a single point in the phase space, quantum objects are fuzzy, that they are distributed over a region of phase space, whose minimum volume is given by the Uncertainty Principle. In the same way, Tarde interpreted the atom as the monad of matter, so we may interpret the Uncertainty Principle as an expression of the monad of volume in phase space.

Uncertainty Principle to exist (characteristic "c"). These actors were laboratory equipment, mathematical formalism, and philosophical doctrines (characteristic "f"). What explains Heisenberg's success and failures were not beliefs nor knowledge, but his ability in articulating propositions (characteristic "d"). His betrayal of Bohr's and Jordan's interpretation may have played an important role in the failure of his interpretation, while the further articulation of the mathematical expression allowed its survival. The fact that the mathematical expression survived with a different meaning exemplifies the fact that non-humans have their own agency independently of human volition (characteristic "b"). In the end, we speculate that the stability of the Uncertainty Principle is due to the fact that Heisenberg introduced, without knowing, a monad of determinacy, agreeing with Gabriel Tarde's claim.

In this sense, we understand that Symmetrical History has the potentiality of allowing us to speak about Physics without having to commit to an internalist or to an externalist approach and without having to assume an absolutist or a relativist perspective. Also, it may allow us not only to describe Physics, but also to provide explanations for its progress according to the stability of associations.

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