Extensionalism, Naturalism, and Probability: Can Quine's Anti-Modalism Survive Quantum Mechanics?

Sara Peppe

PhD

University of York

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Abstract

This thesis highlights a major fault in Quine's philosophy. I argue that Quine's combination of extensionalism and naturalism cannot be maintained due to the role played by probability in Quantum Mechanics (QM), and that attempts to save Quine's perspective fail, requiring Quine to drop either extensionalism or naturalism.

Chapter I examines Quine's perspective on modality and retrieves the few passages where probability is involved. I consider Quine's treatment of dispositions and underline that probability is intended by Quine either as subjective degrees of belief or, in the case of QM, as propensity, where this is still thought by Quine to be extensional.

In Chapter II, I make preliminary remarks about the available interpretations of probability considering that the majority of them cannot be used to make sense of QM probability in the Quinean system.

In the third chapter, after having considered the interpretations of QM, I examine Heisenberg's potentialities that ground his understanding of probability in QM. I argue that potentialities as conceived by Heisenberg cannot be understood in any extensionalist way. Relying on this, I propose two scenarios from QM where *de re* modality is involved.

Chapter IV presents a potential solution for Quine involving Lewis' Best System account of laws of nature. I underline that even if Lewis' system proposes a clear extensional framework it presents major drawbacks when it comes to combining it with Quine's naturalism.

The discussion on potential solutions to preserve Quine’s account continues in Chapter V, where I consider Quantum Bayesianism (QBism) that endorses subjective probability in QM. Also in this case, major discrepancies with the Quinean perspective are found with particular reference to the role of the Born Rule.

On this basis, the solution of the flaw appraised in Quine's systems might involve the abandonment of either extensionalism or naturalism.

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Author’s declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

Introduction

This thesis brings to light an inherent contradiction in Quine's philosophical account detailing it in view of the role of probability in Quantum Mechanics (QM). Also, the thesis argues that attempts to implement alternative perspectives on probability in the Quinean philosophy, preserving both extensionalism and naturalism, fail; leading to the conclusion that to preserve coherence in the Quinean philosophical *corpus* either extensionalism or naturalism should be removed. The goal of the thesis is to explore the theme of probability in Quine's speculation and shed light on it while taking into account QM discoveries, and examine Quinean probability through the lens of these discoveries. While Quine's treatment of probability is very quick, the growing consensus on the centrality of objective probabilities in such a successful field of physics, i.e., QM, necessitate a deep examination of the Quinean attitude towards probability given his commitment to naturalism and to the idea that philosophy is in continuous with science; thus, informed by science.

With regards to probability, Quine's speculation focuses on it in a few sparse passages with the majority of work done on the theme that is performed by Quine within his general account of modality. Modality is a pivotal subject in the Quinean philosophical *corpus.* Indeed, modality is treated deeply and thoroughly by Quine; with Quine energetically committed against modality. Specifically, Quine's philosophical work aims for a strong rejection of modal intensional contexts with the final objective of restoring extensionality. While extensional terms deal with the real thing an object refers to, intensional contexts involve the inherent meaning of a term. Meaning, in turn, is considered by Quine an unclear and ambiguous concept.

Either by rejecting modality directly as occurs in the case of *de re* modalities, related to the essence of a given thing, or by extensionalising, as in the case of *de dicto* modalities (which are about the way something is expressed), Quine is committed to refusing modality relentlessly throughout all of his speculations. The process of extensionalising intensional contexts takes place by using *ad hoc* logical devices, and, this process that applies to modality is likewise applied to probability. Indeed, probability statements are extensionalised in the Quinean philosophical system to pursue the idea of using first-order logic only and preserve in this way a pure extensional framework, where each term relates to a real object. First-order logic, which has a major role in the Quinean speculation, is also used to regiment our theory of the world (i.e., all of our best scientific theories). Here comes into play Quine's naturalism that prescribes that we ought to believe in the existence of the entities posited by our *corpus* of best confirmed theories of the world. In other words, Quine's naturalism presupposes that our best scientific theories indicate to us what exists, this means that our ontology is fully dependent on science. And, in turn, science dictates what ontology we ought to believe in.

Problems arise with the development and deployment of QM. QM is a theory of physics that deals with the description of nature at the atomic and subatomic level, which developed around the early 20th century. Interestingly, QM as standardly understood implies indeterminism and quantum mechanical measurements deal with probability; indeed, QM measurement outcomes are expressed in the form of probabilistic predictions only. Plus, QM works efficiently the way it is, allowing for precise predictions of QM phenomena, which is clearly what physicists strive for.

All of this, poses a non-negligible issue to Quine's treatment of modality and support of extensionalism combined with his naturalism. This occurs because, it seems that QM probabilities are not just *de dicto* modalities but *de re.* The thesis examines the idea that probability in QM exemplifies the third grade of modal involvement, where a commitment to *de re* modality is involved. In a Quinean naturalist light, we ought to believe in our demonstrated theories of science and among those QM is undoubtedly included. Therefore, we appraise that the combination of Quine's naturalism and extensionalism and the way probabilities are intended in QM seem to be conflicting. Hints on the contrast between the Quinean system and QM are perceived by Quine. Indeed, it will be noted that Quine marginally mentions that his system that commits to subjective probability could run into problems with probability in QM and turns his attention to the propensity account of probability specifying that extensionality is still needed and should be preserved anyway.

Unfortunately, Quine did not develop the above mentioned point further. This thesis attempts to make sense of this, evaluating whether preserving the combination of extensionalism and naturalism is feasible. This will be done also considering the potential implementation of other philosophical perspectives into Quine's philosophical system. This thesis considers several philosophical accounts of the role of probability in QM that might look attractive as ways of preserving the Quinean combination of extensionality and naturalism in light of the probabilistic nature of QM. Amongst the theories taken into account in the attempt to solve the inherent contradiction in Quine's philosophy, some of them will be treated very briefly acknowledging that their very well-known drawbacks would prevent them from being considered functional for including them into the Quinean systems; among those we find frequentism and the propensity view of objective probabilities. In particular, it will be argued, contra Quine’s own assumption, that a propensity account of QM probabilities involves implicit modal assumptions that cannot be extensionalised. Longer and deeper treatments of Lewis' Best System account of laws of nature and Quantum Bayesianism (also known as QBism) are taken into account to look for potential ways out for Quine. Indeed, some aspects of both the Best System account of laws of nature and QBism present interesting starting points for discussion on the potential inclusion of them in the Quinean system. But, the thesis highlights that major and crucial issues prevent us from relying on the Best System account of laws of nature and QBism to resolve Quine's issues.

Therefore, the thesis concludes that saving both naturalism and extensionality is unfeasible.

Outline of the Thesis

Chapter I of the thesis is an investigation of Quine's cornerstones of extensionalism and naturalism. While section A, is dedicated to a very brief and general consideration on the role of probability in QM to introduce the reader to the issue, section B is dedicated to an in-depth analysis of Quine's speculation, evaluating the aspects of importance for this thesis in a step-by-step process. In section A of Chapter I, I deal with the basic aspects of probability in QM, including an overview of the wave-function. Section B analyses Quine's viewpoint on extensionalism together with his account of naturalism, drawing on the cornerstones of Quine's perspective. I emphasise that Quine's naturalism leads him to think that our best scientific theories tell us what we ought to believe exists, and that the scientific statements included in our best scientific theories should be taken to be true, leading us to think that our ontology depends on science. Quine advances the proposal of adopting first-order logic as the right language for science, ruling out modality in this way and obtaining a system completely clear of modalities. A clear description of what is considered to be Quine's viewpoint on modality and his ontology is given [B.1, B.1.1 and B.1.2]. After that, it will be highlighted Quine's perspective on modality in physics underlining that as occurs with probability, Quine does not deeply treat the issue, instead, he hastily treats the theme evoking again the need of extensionalising modal contexts in physics too [B.2, B.2.1, B.2.2]. Interestingly, Quine dedicates a paragraph of *Word and Object* (1960 pp. 222-226) to dispositions. The above-mentioned treatment of dispositions provides the ground for considerations on whether Quine's dispositions can be used as such as a viable way to understand quantum probabilities as extensional propensities. A first few remarks on a potential move in this direction will be considered in B.2.3 and B.2.4. After having considered these aspects, a discussion on Quine's three degrees of modal involvement is presented, detailing all the three grades of involvement with modality and outlining Quine's argument that the third degree of modal involvement cannot be extensionalised, and, thus, should be rejected straightaway as Quine (1966) points out. I will also present Smokler's perspective on probability, outlining and defending his argument for concluding that probability exemplifies the problematic third degree of modal involvement (Smokler, 1977). In addition, in section B, it is clarified that modality and probability can be considered co-extensive [B.3, B.3.1, B.3.2, B.3.4, B.3.5]. Section C is dedicated to critiques to Quine's account of modality in science and it is underlined that these critiques provide a good starting point but more needs to be done to have a clearer picture of the issue affecting Quine's philosophical account [C, C.1., C.2., C.3].

Chapter II examines Quine's "dual" account of probability and the available interpretations of probability in philosophy. Section A is dedicated to Quine's subjectivist account of probability taken into account in *From Stimulus to Science* (1995) and Quine's proposal of interpreting probabilities in QM as extensional propensities. This has been hinted in *Confessions of a Confirmed Extensionalist and Other Essays* (2008) [A, A.1, A.2]. Section B is focused on physical, epistemic and subjective probability. After that, the majority of the chapter is focused on the various available philosophical perspectives on probability, giving attention, especially to subjective probability since it has been favoured by Quine in his first attempt to define probability. Indeed, this position was maintained by Quine till the end of his career when he decided to opt for the propensity view in the light of QM developments [C, C.1]. Moreover, a close look to the subjectivist account of probability turns out to be particularly fruitful in the light of the following arguments of this work. Indeed, QBism proposes to interpret QM probabilities in subjectivist terms [C.1.1].

Also, given Quine's abandonment of subjective probability in favour of an objectivist account of probabilities, i.e., extensional propensities, attention will be paid to objective probability [C.2]. Part of the chapter is devoted to frequentism, which is an extensional view of probability without being deemed to be a subjective interpretation of probability. But in the case of the frequency view, there are some issues with QM probabilities being unable to account for single-case probabilities [C.2.1]. Sub-sections C.3, C.3.1 and C.3.2 are dedicated to the propensity view even though, it is noted that in its classical formulation, it would not be compatible with Quine's need for extensionality. The chapter concludes with a small discussion on Popper's propensities and Aristotle's potentialities as a way to introduce the theme of Aristotelian viewpoint in Quine's speculation as well as in QM that is taken into account in Chapter III [C.3.3].

Chapter III is a grounding chapter of this thesis where, after a general outlook on the available interpretations of QM, a deep argument on how probability in the standard interpretation of QM exemplifies the third degree of modal involvement is conducted. Section A is entirely dedicated to the current interpretations of QM to have a grasp on the current advancements in the field. Moreover, a study on the Copenhagen interpretation of QM is presented, in order to understand what is implied in the standard interpretation of QM. Section B is dedicated to the relationship between Aristotelian essentialism and Heisenberg's viewpoint on tendencies, considered as grounding probabilities in QM [B, B.1, B.1.2]. Moreover, an examination of Aristotle's *potentia* and essential and accidental attributes is given [B.2]. As considered in Chapter II, the first and the second degree of modal involvement are unproblematic for Quine given the fact that they could be extensionalised while the third degree is not extensionalizable. Quine's rejection of the third degree of modal involvement deals with Aristotelian essentialism [B.3]. And, as recalled in *Physics and Philosophy: The Revolution in Modern Science* (1958) Heisenberg's viewpoint takes into account the idea that propensities have something to do with Aristotelian essentialism. In other words, Heisenberg thinks that probability in QM is related to microscopic objects' essences, which is in contrast with Quine [B.3.1]. Moreover, a small survey on philosophical perspectives that share Heisenberg's thoughts is conducted [B.4, B.4.1, B.4.2, B.4.3]. In B.5, it is remarked that since science tells us what exists, if it tells us that essential properties exist then we ought to believe in the existence of essential properties. After that, I argue that standard QM leads to the idea that there are essential properties in nature. I propose an argument that takes into account the probabilistic nature of electrons that are measured half of the time spin-up and half of the time spin-down [B.5.1]. After that, I compare Quine's dispositions and Heisenberg's potentialities while demonstrating that Quine's account of dispositions is unavailable to be used for QM [B.5.2, B.6].

Chapter IV presents David Lewis' Best System account of laws of nature [A] and this thesis argues against its implementation in Quine's philosophy to make sense of probability in QM while maintaining both extensionality and naturalism. Lewis' perspective on laws of nature and his Best System account have been examined in this work because of Lewis' advancement of a novel kind of propensity view, where propensities are extensional. A brief treatment of modal realism and Lewis' attitude to quantification is taken into account together with his perspective on subjective probability, chance and laws of nature [A- A.3.1]. Specifically, the thesis' purpose of considering the above mentioned peculiar characters of Lewis' viewpoint to uncover general main points of divergence with the Quinean picture is shown right from the beginning, i.e., in paragraph A.1. After that, Humean Supervenience with its grounding aspects is evaluated [A.4]. Also, in sub-section A.4.1, a discussion is performed on the constituents of the Humean base, making sense of what the Humean base is. In this part of the chapter, it is also highlighted that Humean Supervenience has been disproven due to Bell's inequalities, which constitute a very well established theorem of physics [A.4.2]. After that, the molecular structure invoked by Quine when treating dispositions and the ban of dispositions from the humean base promoted by Lewis are compared [A.4.3 and A.4.4]. Sub-section A.5 evaluates whether Lewis could be considered a Quinean naturalist clarifying that they are very different and surely irreconcilable. Moreover, it has been underlined that Lewis' main concern is to find a valuable and non-contradictory philosophical theory making clear that it is not crucial for him that his perspective is in line with physics. This point is dramatically in conflict with Quine's naturalism (according to which our demonstrated scientific theories tell us what exists). The chapter concludes making clear that even though Lewis' account seemed to be promising at first representing a potential way out for Quine, in the end, it has been found that Lewis' account is not in line either with Quine's overall philosophical account and also with QM, with its crucial issue of non-locality, which represents the major problematic point in the discussion.

Chapter V of the thesis evaluates another possible way of solving the Quinean contradiction highlighted in the very first phases of this work. This potential way of dealing with Quine's issues looks at Quantum Bayesianism, i.e., QBism. QBism is a novel interpretation of QM, which is constantly updated as we notice if we look at ‘Ideas Abandoned en Route to QBism’ (Stacey, 2019). QBism proposes a new way of intending probability in the quantum mechanical field and carries important philosophical implications such as the possibility of interpreting probability in a subjectivist way so as to clear out the puzzling aspects of QM (including decoherence and the measurement problem). More specifically, QBists believe that we could interpret the probabilistic behaviour displayed by microscopic particles in a subjectivist way. This means that in a pure Bayesian light, QBists think that probability represents our subjective degrees of belief. In other words, probability is the degree of credence one has in a given outcome. This allows QBists to get rid of phenomena like quantum entanglement and non-locality that simply do not exist in the eyes of QBist proponents. QBism appears as a promising solution to the Quinean issues with QM since it could have supported Quine's subjective probability. On these premises Chapter V delves into QBism evaluating a few major aspects of this interpretation of QM. Before considering QBism, subsection A.1 is devoted to recalling Quine's ontology to pursue a subsequent comparison with the QBist one to highlight the role of mathematics in the Quinean speculation, since it will be dedicated part of the chapter to pondering QBism perspective on mathematical entities underlining that QBism perspective on the mathematical entities is not entirely clear, as assumed in B.3.

Following this, the remaining portion of section A is devoted to the treatment of QBism. In particular, A.2 takes into account some general characteristics of QBism. A.2.1 looks at the QBist ontology and A.2.2 evaluates the major advantages and drawbacks of QBism as perceived in the philosophical community. Plus, in the above mentioned part of the fifth chapter it is briefly mentioned a major concern on the Born Rule that would prevent the implementation of QBism in Quine's philosophy deepened further in section B.

Section B, looks at the potential inclusion of the QBist treatment of probability in Quine's philosophical account, addressing various arguments against a Quinean adoption of QBism. The puzzling aspects that prevent us from using QBism as a way of solving Quine's puzzles are treated in increasing order of problematic nature. Therefore, B.1 evaluates how QBism is perceived in the philosophical and physical community considering a poll that reveals that this view is not currently accepted by the majority of physicists who continue to use the Copenhagen interpretation, with QBism being seen as a niche viewpoint, albeit one which relies on the same mathematics as standard QM. This means that QBism remains just an interpretation of QM and not an alternative theory that presupposes an extensional interpretation of probability. Also, Quine's perspective on philosophical speculation is recalled, noting that for Quine philosophy should be seen as continuous with science. In subsection B.2, the ontological commitments of QBism are taken into account, underlining that the ontology proposed by QBists is very meagre and remains silent on the existence of micro-objects too. Subsequently, we will consider the QBist perspective on the existence of mathematical objects, noting some worrying subjectivist elements about the picture of mathematics in QBist writings. It will be argued that the doubts on the subjectivity of mathematics are only partially clarified by a private correspondence, with some unclarity on whether mathematics in general is to be taken as subjective in the QBist view remaining in place [B.3]. The main argument against the use of QBism to clear the incoherence in the Quinean philosophy is disclosed and developed in B.4, where the QBist treatment of the Born Rule is taken into consideration. In this part of the chapter, it is highlighted that the Born Rule intended in the QBist way, i.e. as a normative constraint on agents' degrees of belief, lacks explanatory power. This is considered as a crucial issue in the light of Quine's theory choice.

Chapter I: Quine's modal scepticism under examination

In this chapter, I explore Quine's attitude towards modality, arguing that probability in QM represents an unacceptable degree of modal involvement in a Quinean framework. In section A, I briefly take into account a few characteristics of probability in QM to give a general overview of the theme. In this part of the chapter, it will be highlighted that QM seems to entail the idea that nature is probabilistic and the probabilistic aspects of QM will be evaluated. In section B, I explore Quine's philosophical cornerstones. Firstly, I consider Quine's extensionalism and naturalism. This discussion is linked to the description of the approach to ontology accepted by Quine. I highlight that Quine's approach to ontology is deeply connected with his naturalism and extensionalism. To sustain my claims about the incoherence of Quine's philosophy when it comes to probability in QM, I examine deeply the concept of modality in logic and physics in the Quinean speculation, underlining that Quine rarely discusses modality in physics, and generally considers it on a par with logical modality. This also occurs when Quine talks about dispositional properties. In this section of the chapter, I also look into the acceptable and unacceptable degrees of modal involvement for Quine, highlighting that probability exemplifies an unacceptable grade of modal involvement. In section C, I consider the wider role of modality in science, defending the idea that science relies on intensionality rather than on extensionality only. I consider that other inherent problems to the Quinean viewpoint have been noted by other scholars. In particular, Hintikka's 'Three Dogmas of Quine's Empiricism' (1997) and Chatti's 'Extensionalism and Scientific Theory in Quine's Philosophy' (2011) underline these additional issues. Firstly, I examine Hintikka's paper (1997) where he is persuaded that the scientific method is a probabilistic, one since hypotheses and conceptualizations are fundamental for physics. After that, I take into account Chatti's article (2011) according to which scientific language is intensional and cannot be extensionalized. At the end of the section, I clarify the importance of the research conducted in this thesis by underlining that it extends the scope of previous researches conducted on the issue of probability and QM in Quine's speculation, offering a new and more complete view on the problem.

Section A: ***QM and probability***

This section deals with general aspects of QM and the role of probability in QM. Section A.1, takes into account some main points of the theory of QM and considers in a general way the main concepts grounding the above mentioned branch of physics, introducing the reader to the probabilistic aspects of QM. This section considers de Broglie's assumptions and the double nature of microscopical bodies that behave as a particle and as a wave. It also takes into account Born's interpretation of the wave function that deals with probability. Additionally, a general description of the Double Slit Experiment, where the wave nature of microscopical objects is shown, is provided. In section A.2, a deeper treatment of the probabilistic aspects of QM is conducted. Specifically, it will be clarified the probabilistic aspect of the wave function and its role. Indeed, it will be highlighted that the wave function cannot determine exactly where to find an electron in a given area. Instead, the wave function offers only probabilistic results, injecting probability in an otherwise deterministic world.

A.1 ***A few aspects of QM***

QM is one of the most central branches of physics that has revolutionised the way we perceive the world. Its origins can be traced back to Louis de Broglie’s assumptions, according to which all matter (massive bodies included) has a wavelength. This peculiarity is clearer in microscopical bodies, and that is why the majority of the experiments on the theme have been conducted on electrons that behave like a circular wave around the atom's nucleus. In order to describe the electron's waves, Schrödinger converted de Broglie's intuitions into an equation. The Schrödinger equation applies to quantum systems and describes systems' multidimensional wave function (containing coordinates for different measurable properties, e.g., position, momentum, spin). Since the above mentioned equation does not explain how the wave function should be interpreted, Born suggested that it can be viewed as telling us the probabilities of certain measurements yielding a particular value. For example, an electron’s wave function can be used to determine the probability that an electron can be found in a certain position in a given system if measured.

The predictions fit with observation. For example, with the Double Slit Experiment, scientists appraised a diffraction pattern that a stream of electrons that passed through a plane with two slits in it left on a screen beyond. When the experiment is conducted the diffraction pattern shows where each electron hits with the diffraction pattern appearing at the act of recording the position of electrons after they go through the two slits and once they land on a screen. From the diffraction patterns recorded, the experimenter is able to infer the probability of an electron arriving at a given spot. In other words, the abovementioned diffraction pattern can be used to deduce the probability of any given electron arriving at a given area of the screen. In addition, the probabilities given by the electron's wave function are in line with what is seen in these diffraction patterns. This, to clarify that the wave function predictions are in line with the observation we discussed in the previous lines. No one knows the exact final position of the electron prior to measurement, indeed we can just know how likely it is for each electron that it will land in a certain area of the screen. In other words, the wave function has a probabilistic nature. All the objects exhibit a diffraction pattern even if the wavelength is inversely proportional to the mass of the objects. That is why Newtonian Mechanics is still successfully used to describe macroscopic phenomena. But this triggers a thought regarding classical mechanics, i.e the Newtonian one. Indeed, given that macroscopic objects are made of microscopic ones, it seems safe to say that classical mechanics is grounded on QM. Indeed, quantum physics is surely the most fundamental branch of physics nowadays. Furthermore, since the quantum realm seems to be probabilistic in nature the idea that nature is probabilistic *per se* seems to be consequential.

A.2 ***The probabilistic elements of QM and the wave function***

Basic concepts of QM will clarify the probabilistic aspect of the above mentioned theory; thus, it is vital here to understand the issue of the role of probability in QM. As noticed by Griffiths (1995, p. 1) classical mechanics is concerned with the determination of the position of a particle at any given time *x(t)*, quantum mechanics has a different approach and looks to determine the wave function of a particle Ψ *(x,t);* to obtain this wave function we solve the Schrödinger equation. As Griffiths notes (1995, p. 2) the Schrödinger equation has a role that is similar to the one played by Newton's second law of motion (considered in the previous lines about classical mechanics). The Schrödinger equation determines the wave function of a given particle for all future times given initial condition, i.e., generally Ψ (x,0) while Newton's second law of motion looks for *x(t)* for all future times (*Ibid*.). As Griffiths (1995 p. 2) underlines, while particles are localised, the wave function is unlocalised being distributed in space. The statistical interpretation of the wave function developed by Born explains how the wave function is able to account for the state of particles (*Ibid*.). Specifically, the statistical interpretation of the wave function determines the probability density $|\Psi\ (x,t)|^2$ that provides the probability of detecting the particle considered at a given point *x* at time *t* (*Ibid*.). Moreover,

> The statistical interpretation introduces a kind of indeterminacy into quantum mechanics, for even if you know everything the theory has to tell you about the particle (to wit: its wave function), you cannot predict with certainty the outcome of a simple experiment to measure its position –all quantum mechanics has to offer is *statistical* information about the *possible* results. This indeterminacy has been profoundly disturbing to physicists and philosophers alike. (Griffiths, 1995 pp. 2-3)

Here, it is worth noting that till now we have focused on position only, but the wave function also contains other information (e.g. the probabilities of measurements of momentum and other properties - e.g. in the electron, its spin values for differently angled axes). Thus, the state considered above contains probabilistic information about all measurable properties of the system being represented, not just position. Thus, QM has to offer only probabilistic results for all of these observable properties, due to the very nature of the wave function. This is why with QM there has been a shift from determinism to indeterminism. More on this is said in Chapter III (subsection A.1.3), where results of Einstein's EPR argument are taken into account. Probability, as noticed above, has a major role in QM and all the experimental results gained through quantum measurements deal with probability.

Establishing whether Quine's account is coherent with physics is a major philosophical issue given that physics plays a pivotal role in Quine's speculation. Pinning down exactly his thoughts on modality, probability and on the role that these two play in physics would be of help in having a clearer picture of Quine's philosophical view.

Section B: ***Quine, modality and probability***

In section B, I argue that probability in QM represents a problematic degree of modal involvement in the Quinean picture. In order to do this, a complete account of Quine's naturalism and anti-modal attitude will be given. In section B.1, I will take into account those aspects of Quine's philosophy most relevant for this thesis, such as his commitments to extensionality and naturalism. In section B.2, I will discuss the role of modality in physics according to Quine's philosophy, as well as the Quinean attitude towards dispositional properties, highlighting Quine's strong rejection of all the forms of modality. In section B.3, I will conduct a discussion on the various degrees of modal involvement Quine takes into account, underlining that, according to Quine, there is an extreme degree of modal involvement that cannot be extensionalised, i.e. the third grade of modal involvement. After that, I will consider probability in QM as an example of the third degree of modal involvement, relying on the idea proposed by Smokler (1977) that probability represents a non-extensionalisable type of modality.

B.1 ***Quine's philosophical cornerstones***

Quine's philosophical perspective on the themes mentioned above is almost entirely summarised in 'On What There Is' (1948), 'Reference and Modality' in *From a Logical Point of View* (1980), 'Dispositions and Conditionals' in *Word and Object* (1960) and 'Three Grades of Modal Involvement' (1966). We will examine these one by one in what follows, with a view to identifying Quine's perspective on modality and probability within his philosophical framework.

First of all, 'On What There Is' (1948) is devoted to answering the question, 'What is there?', and to demonstrating that we cannot meaningfully differentiate between existent objects and non-existent objects among those we quantify over. So, to avoid commitment to some problematic seeming objects, Quine paraphrases talk that seems to be committed to such objects. In this way, seemingly non-existent objects are no more quantified over. Indeed, Quine in ‘On What There Is’ (1948) wants to clear out the seemingly referential use of singular terms through paraphrase: substituting the singular term with a descriptive expression *à la* Russell, “Russell, in his theory of so-called singular descriptions, showed clearly how we might meaningfully use seeming names without supposing that the entities allegedly named be" (Quine, 1948 p.25). Similarly, general terms can be paraphrased and used without assuming their existence. This leaves the existential quantifier as the sole indicator of ontological commitment.

The concept of quantification, which is pivotal in Quine's speculation, is linked to first-order logic (and second-order logic, even though Quine prefers to do without it), which extends propositional logic (made of simple atomic sentences and truth values attributed to these sentences) by the use of the quantifiers, i.e. "for all" and "there exist". According to Quine's philosophical project, first-order logic should be applied to the theory of the world that is the *corpus* of our demonstrated scientific theories, to guarantee clarity and obtain a systematised body of knowledge. Moreover, according to Quine, applying first-order logic to the theory of the world has another advantage: it guarantees extensionality. Indeed, Quine backs strenuously this line of thought, according to which scientific language should be extensional. The term "extensional" refers to the extension of a term that is represented by the real thing a term refers to. Consequently, the extension of a sentence deals with its truth values. On the contrary, the intension of a term is its meaning, which is a very obscure and intricate concept for Quine. To explain the difference between the extension and the intension of a term, Quine recalls the very famous Fregean example of the "Morning star" and the "Evening star". In this case, we are referring to the same thing (Venus) but the meaning of these two locutions is completely different.

> Frege's example will serve: the phrase 'Evening Star' names a certain large physical object of spherical form, which is hurtling through space some scores of millions of miles from here. The phrase 'Morning Star' names the same thing, as was probably first established by some observant Babylonian. But the two phrases cannot be regarded as having the same meaning; otherwise that Babylonian could have dispensed with his observations and contented himself with reflecting on the meanings of his words. The meanings, then,

> being different from one another, must be other than the named object, which is one and the same in both cases. Confusion of meaning with naming not only made McX think he could not meaningfully repudiate Pegasus; a continuing confusion of meaning with naming no doubt helped engender his absurd notion that Pegasus is an idea, a mental entity. (Quine, 1948 p. 28)[1]

Moreover, Quine also specifies that “there is a gulf between meaning and naming even in the case of a singular term which is genuinely a name of an object” (*Ibid.*). Quine also believes that defining what meanings are is a “a moot point” (Quine, 1948 pp. 28-29) and a few lines later adds:

> However, I feel no reluctance toward refusing to admit meanings, for I do not thereby deny that words and statements are meaningful. McX and I may agree to the letter in our classification of linguistic forms into the meaningful and the meaningless, even though McX construes meaningfulness as the having (in some sense of 'having') of some abstract entity which he calls a meaning, whereas I do not. (Quine, 1948 p. 30)

Quine's treatment of meaning is strictly linked to his aspiration to extensionality. And, in ‘On What There Is’ (1948, pp. 31-32), Quine clearly says that the use of bound variables is the only way to commit ourselves to an ontology. He also highlights that:

> a theory is committed to those and only those entities to which the bound variables of the theory must be capable of referring in order that the affirmations made in the theory be true. (Quine, 1948 p. 33)

Thus, according to the Quinean framework, extensionality must be guaranteed and intensionality that deals with meanings should be rejected or extensionalised, as it will be considered in the next paragraphs.

Prior to deepening this discussion, more is needed in terms of explaining the concepts of extensionality and intensionality. In order to have a clearer understanding of intensionality and extensionality, we need to take into account a few basic concepts that appear in the Quinean system. First of all, Quine (1966 p. 158) makes a distinction between purely referential and non-referential occurrences of singular terms in a statement. An occurrence of a singular term in a sentence is

1 In the cited paper, McX represents the philosopher who confuses naming and meaning.

purely referential if the singular term's function, in that given sentence, is to refer to an object, and Frege's parameter to determine whether an occurrence is purely referential is substitutivity of identity (Ibid.). Quine (Ibid.) makes it clear that occurrences enclosed in quotation marks are usually not purely referential. After having made this first distinction, Quine talks about contexts, which can be either referentially opaque or transparent. Referentially opaque contexts are those able to turn a purely referential occurrence enclosed in a statement into a non-purely referential one once the given statement is put in the opaque context (Ibid.). In other words, "a context is referentially opaque if it can render a referential occurrence non-referential" (Quine, 1966 p. 159). Quine (*Ibid*.) explains that quotational contexts are referentially opaque; thus, they have no logical status and should be paraphrased to get rid of the referentially opaque aspect when "irreferential occurrences draw undue attention" (*Ibid*.). More on how Quine paraphrases contexts, is said in C.2. Now, we keep following Quine's discussion that leads to the definition of intensionality and extensionality. In order to understand extensionality and intensionality, we need to consider the case of the occurrence of a statement within a longer statement. The occurrence of a statement within a larger statement is defined as truth-functional if, in case we change the statement with another statement that has the same truth value, the truth value of the containing statement is preserved (*Ibid.*). This leads to the fact that occurrences of statements within larger statements are not truth-functional within referentially opaque contexts (e.g. quotations) (*Ibid*.). Now, Quine (1966 p. 160) gives the definition of extensionality and says that a policy of extensionality is "a policy of admitting statements within statements truth-functionally only" (*Ibid*.) and makes the important clarification that quotational contexts that are referentially opaque can be harmonised with extensionality through paraphrasing them (*Ibid*.). Anyway, we can derive from the concept of extensionality the definition of intensionality that occurs when statements within other statements are not introduced truth-functionally only.

For the purpose of this work, we need to look at the concepts considered above in the light of Quine's critique of modal logic. As has been noted above, according to Quine, failure of substitutivity of co-referential statements designates opaque contexts; this comes with another characteristic of opaque contexts, i.e, the incoherence of quantifying into them, with modal contexts seen as opaque contexts in the Quinean speculation (Ballarin, 2012 p. 239). A general example of the failure of substitutivity into modal contexts and the consequent opaqueness of these contexts is given by the very common example of the number of planets and the number nine. Taking into account necessity we have N (9>7), which is a true sentence, but this sentence turns out to be false if we substitute ‘9’ with ‘the number of planets’. In this case we would have N (the number of planets >7), which is clearly false since the number of planets is not necessarily greater than 7.

Moreover,

> Quine connects *incoherence* of quantification-in to failure of substitutivity of co-referential terms, because this failure is seen as indicative of a problem affecting the entire linguistic context in which the terms are set, not just the terms (*Ibid*.).

Therefore, we notice that the problem of substitutivity that occurs with modal contexts is an issue of linguistic contexts as a whole for Quine, and as Ballarin (2012, p. 242) underlines, Quine considers the incoherence of quantifying into modal contexts and the loss of substitutivity as two sides of a coin. Thus, the linguistic aspect for Quine plays a crucial role. Moreover, the discussion on quantification into modal contexts is strictly related to another unwanted aspect, i.e., essentialism, according to which we can attribute properties to objects disregarding how they are referred to, i.e. their linguistic context. A deeper discussion on essentialism and Quine’s aversion to it is performed in the next paragraphs [B.2.1, B.3.1 and B.3.2].

B.1.1 ***Quine’s naturalism and physicalism***

Combining Hylton's work on Quine (2007 pp. 298-323) and ‘On What There Is’ (1948), we can evaluate Quine’s ontological perspective. Indeed, Quine’s purpose is to purge from our ontology all the entities that we do not quantify over in our best scientific theories and to claim that we are committed in our ontology to all and only objects quantified over in the above mentioned theories. Moreover, according to Quine's naturalism “it is within science itself, and not in some prior philosophy, that reality is to be identified and described” (Quine, 1981 p. 21). Naturalism is linked to physicalism, and Hylton (2007) dedicates a paragraph of his work on Quine on physicalism, where he underlines that Quine's physicalism involves commitment to the existence of both physical objects and abstract mathematical entities (p. 310). Therefore, Quine's physicalism diverges from “regular” physicalism, according to which only physical (in the sense of ‘spatiotemporal’) objects exist. “Regular " physicalism is rejected by Quine who is ontologically committed to abstract mathematical entities in addition to physical objects due to the role played by mathematical objects in our best scientific theories. ‘Physicalism’ then, for Quine, is a commitment to the objects quantified over in our physical theories.

Specifically, according to the regular physicalist perspective:

> Physicalism is, in slogan form, the thesis that everything is physical. The thesis is usually intended as a metaphysical thesis, parallel to the thesis attributed to the ancient Greek philosopher Thales, that everything is water, or the idealism of the 18th Century philosopher Berkeley, that everything is mental. The general idea is that the nature of the actual world (i.e. the universe and everything in it) conforms to a certain condition, the condition of being physical. Of course, physicalists don’t deny that the world might contain many items that at first glance don’t seem physical — items of a biological, or psychological, or moral, or social, or mathematical nature. But they insist nevertheless that at the end of the day such items are physical, or at least bear an important relation to the physical. (Stoljar, 2021 p. 1)

On the contrary, Hylton (2007 p. 310) clarifies that, in the Quinean framework the term physicalism is not used for the philosophical doctrine that allows for the existence of physical (i.e. spatiotemporal) entities only. Instead the above mentioned doctrine is called by Quine “materialism” (*Ibid.*), while as mentioned above, physicalism involves the existence of physical and mathematical entities.

B.1.2 ***Naturalism, ontology and our theory of the world***

Quine’s account of logic is tightly connected to his ontological viewpoint. Indeed, the theory of the world, which is the *corpus* of our best confirmed scientific theories, establishes which entities we ought to believe to exist. In a nutshell, according to Quine, we should accept that all the objects quantified over in our best formulation of our theory of the world exist or, as Hylton hints (2007 p. 304), that all the objects useful for the theory of the world exist. Given that Quine is concerned with the ontology of the regimented theory, he believes that the only entities allowed are those posited by the regimented theory. For this reason, no entities are given before the theory. In other words, objects are posited not given. As a consequence of this, entities entitled to be part of the Quinean ontology are only physical objects and abstract mathematical entities that are not posited *a priori* (as already underlined in the previous lines), as these are the entities we find quantified over in our best physical theories. With regards to physical (in the sense of spatiotemporal) objects, Hylton cites Quine’s ‘Whither Physical Objects?’ (1976) and says that they are "the aggregate material content of any portion of space-time" (Hylton, 2007 pp. 301-302), which means that physical objects are not just bodies but a conjunction of bodies and states. While with regard to mathematical entities, these are simply sets, in which numbers and functions are included (given that numbers and functions can be reduced to sets). Thus, the two above mentioned categories of entities are accepted only because they are useful for our best scientific theories and the utility for the theory of the world is the main and only principle according to which Quine chooses what objects are entitled to be a part of the ontology.

Hylton (2007 pp. 298-323) traces the evolution of Quine's ontology, highlighting that Quine maintained the same spirit throughout his speculation, founding his ontology on the entities posited by our best theory of the world. This led Quine to study the possibility of having an ontology made by sets only because of their role in our best scientific theories (Hylton, 2007 pp. 304-310). The above mentioned position is called hyper-Pythagoreanism, which is not deepened thoroughly by Quine but represents an important cornerstone of Quine’s philosophy, with Hylton (2007 p. 307) underlining that Quine in ‘Whither Physical Objects?’(1976) is not concerned with the idea of whether the ontology accepted is made of sets only or sets with physical objects. This aspect of the Quinean philosophy shows that there are two other main characteristics of Quine's viewpoint: the importance of the economy of the theory and reductionism. These two aspects are linked, with Hylton (2007 pp. 307-308) noting that “Quine favours economy” and that “The general moral here is that there is less to ontology than meets the eye”, with the ontology made of the minimal collection of entities that have a role in our scientific theories.

Given Quine's emphasis on the role played by science, one could ask: what does

Quine intend by the term 'science'? This term in Quine's framework is used in a broader sense to indicate several subjects (in which biology, history, sociology etc. are included) but physics plays a key role and it is paradigmatic (Hylton and Kemp, 2020).

In *Theories and Things* (1981 p. 98), Quine illustrates this point saying:

> nothing happens in the world, not the flutter of an eyelid, not the flicker of a thought, without some redistribution of microphysical states ... Full coverage, in this sense, is the business of physics, and only of physics.

This indicates the importance attributed by Quine to physics. For this reason, Quine's viewpoint on modality and probability in physics is crucial to making sense of his philosophy.

B.2 *Quine examines modality in physics*

The theme of modality in physics is considered in two Quinean works: ‘Reference and Modality’ in *From a Logical Point of View* (1980) and ‘Dispositions and Conditionals’ that is a paragraph of *Word and Object* (1960). I will also discuss in this context Smokler’s ‘Three Grades of Probabilistic Involvement’ (1977), where probability in science is considered as exhibiting what Quine takes to be a problematic degree of modal involvement. Smokler’s argument will be considered in Section B.3.

With regards to ‘Reference and Modality’ (1980), the issue of modality in physics concerns the language used. Issues like contrary to fact conditionals (i.e. conditionals that contain an if-clause that is contrary to facts) and quantification are involved once again. Thus, all the intensional contexts in physics should be extensionalised, similarly to what happens in logic, as we can see in the last part of the article that will be considered in the next lines. Quine comes to his conclusions on modality in physics, starting from logic and considering the principle of substitutivity, according to which names that refer to the same objects are interchangeable and they can be substituted *salva veritate*. Consequently, Quine takes the opportunity to claim that the principle of substitutivity is untenable where the name that should be substituted is not purely referential, i.e. when it does not refer to a real object but to the name itself. In this case, one should use quotation marks to designate an expression as a name that does not refer to a real entity. Indeed, “An expression which consists of another expression between single quotes constitutes a name of that other expression; and it is clear that the occurrence of that other expression or a part of it, within the context of quotes [...] is not referential, not subject to the substitutivity principle." (Quine, 1980 p. 140), Quine clarifies this considering the statement " 'Cicero' contains six letters", in this case, we can appraise that the name within quotation marks is not referential, indeed, this is a statement about the expression ‘Cicero' and not about Cicero himself. The contexts that are not purely referential, are named by Quine referentially opaque and they are generated by expressions such as "believes that", "thinks that", "doubts that", "because" etc. and also by modal contexts (Quine, 1980 pp. 142-143). Given that the problem of referential opacity is deeply connected to the ontology accepted (i.e. what objects are admitted as possible objects of reference), Quine considers the problem of quantification into opaque contexts, too.

B.2.1 ***No quantification into opaque contexts***

Regarding the issue of quantification into intensional contexts, Quine is persuaded that one cannot quantify into contexts that are referentially opaque since it would lead to nonsense (1980). Moreover, Quine contends, all of those philosophers who accept a quantified modal logic commit themselves to Aristotelian essentialism (*Ibid.*). According to Aristotelian essentialism, objects have essential and accidental properties. In other words, essential properties characterise the essence of an object, i.e. without these, the object would not be as it is, while accidental properties are not necessarily inherent to the essence of objects (*Ibid.*). For example, Quine in ‘Two Dogmas of Empiricism’ (1951) highlights that according to Aristotle being rational is an essential property of human beings while being two-legged is not. The reason why Quine does not accept Aristotelian essentialism is that it is grounded on a modal concept: necessity (Quine, 1980). Indeed, saying that an object has some essential properties means that it necessarily has to possess them to be itself (*Ibid.*). Thus, Aristotelian essentialism is deeply connected with the concept of *de re* modality that occurs when the modal operator relates to a predicate. But, the use of quotation marks is possible only with *de dicto* modalities, namely when the modal operator is attached to a statement. In other words, when the modal nature of the term is not *de re*. Indeed, as pointed out in 'Three Grades of Modal Involvement' (1966), only *de dicto* modalities can be accepted in the Quinean system since they can be paraphrased and assumed as simple linguistic objects. A fuller discussion on this will be performed in the next lines of the chapter [B.3.1 and B.3.2].

B.2.2 ***Quine's remarks on modality in physics***

In the last part of 'Reference and Modality' (1980), Quine briefly talks about physical modality, as I already said before, and he asserts that the first thing to do would be to clarify the above mentioned notion. After that, one should investigate whether physical modalities should be treated like logical ones. For this purpose, Quine underlines that the issue of modality in physics takes into account the concepts of contrary-to-fact conditionals (counterfactuals) and quantification. For this reason, the problem presented by physical modality concerns language, similar to what happens with logical modalities. Quine clarifies that the majority of the discussion pursued in 'Reference and Modality' (1980 p. 158) is referred to strict modality but also specifies that:

> For other sorts, for example, physical necessity and possibility, the first problem would be to formulate the notions clearly and exactly. Afterwards we could investigate whether such modalities, like the strict ones, cannot be quantified over without precipitating an ontological crisis. The question concerns intimately the practical use of language. It concerns, for example, the use of the contrary-to-fact conditional within a quantification, for it is reasonable to suppose that the contrary-to-fact conditional reduces to the form 'Necessarily, if *p* then *q*' in some sense of necessity.

Through the example of solubility in water, Quine demonstrates that in physics expressions like "if x were in water then x would dissolve" involve quantification into modal contexts since this statement expresses a necessity. It can be expressed as "necessarily if x is in water then x dissolves". Importantly, Quine on the last page of the paper admits that "we do not know whether there is a suitable sense of 'necessarily' into which we can so quantify". The approach adopted in this paper is the same one embraced in 'Dispositions and Conditionals' (1960).

B.2.3 ***Bodies' dispositions and modality***

In 'Dispositions and Conditionals' (1960), dispositions are considered as non-manifest properties of a body (e.g. sugar is soluble in water). Indeed, according to Quine, since objects manifest dispositional properties only in a certain condition, it appears that dispositions should be considered as counterfactual conditionals, also named as subjunctive conditionals (*Ibid.*). Quine points out that there is a clear difference between the subjunctive conditional and an ordinary conditional; in the latter one, the antecedent (i.e. the if-clause) can be considered true or false while subjunctive conditionals' if-clauses are false (*Ibid.*). The difference between the subjunctive conditional and the ordinary conditional with false antecedents is that a subjunctive conditional may be true or false while an ordinary conditional with a false antecedent is automatically true, so the subjunctive one can be still affirmed or denied. Quine states that defining an object as water-soluble on the face of it seems to say that if it were in water it would dissolve. In other words, "The subjunctive conditional is seen at its most respectable in the disposition terms. To say that an object *a* is (water-) *soluble* at time *t* is to say that if *a* were in water at *t*, *a* would dissolve at *t.*" (Quine, 1960 p. 222).

Given Quine's scepticism about modality, an alternative account of dispositions is required to avoid the apparent modality in the subjunctive conditional (i.e., its interpretation as 'necessarily, if x is in water, it dissolves'). Quine underlines here that to render extensional a dispositional term we could rely on the so-called subvisible structure: something is soluble if it shares a subvisible structure with something that dissolves: "The difference is that here a stabilising factor is intruded: a theory of subvisible structure. What we have seen dissolve in water had, according to the theory, a structure suited to dissolving; [...] Dispositions [...] are conceived as built-in, enduring structural traits" (1960 p. 223). Thus, according to the theory of subvisible structure, soluble things or fragile objects have a structure fit for melting or breaking, respectively. The same consideration can be drawn for other dispositional terms. In other words, dispositions are nothing but "structural traits" of an object and the dispositionability of a term can be found in the suffix -ble at the end of the term (Quine, 1960 p. 225). In order to discard the dispositional character of a term, since it expresses nothing but a subjunctive conditional as we considered before, Quine believes that we should extensionalise dispositional terms using the operator "M" that means "alike in molecular structure" and the verb from which the dispositional term derives, tenseless. For example, "x is breakable" is paraphrased as ∃y (xMy and y breaks). Quine's desire of extensionalizing dispositional contexts is maintained in *The Roots of Reference* (1974 p.10) where he underlines the need for extensionalizing dispositional terms.

B.2.4 ***A thought on dispositions***

This discussion about dispositions triggers a further remark on why objective probability is a problematic degree of modal involvement for Quine. As just considered, dispositions are intended by Quine as potentialities that are in the objects themselves. So, we could say that dispositions or propensities as they are, cannot be accepted by him because potentialities cannot be found in reality itself. Indeed, what is real is not a simple potentiality: it is, in fact, present in the thing. Saying, for instance, that some person has an 80% risk to develop an illness in old age does not mean that the illness is already present in her body and will appear sometime in the future. The person can have an 80% risk of developing this condition without developing it during her whole life. So, this 80% just expresses expectation, it does not reveal anything about the reality itself. But Quine, considering the straightforward worry that using propensities would allow modality, overcomes this challenge simply taking into account an *ad hoc* concept, namely the physical substructure that helps him to get rid of the vague modal nature of potentialities allowing him to use the paraphrasing tool. But, there is a much more perilous challenge to Quine's viewpoint. Indeed, Quine's account of dispositions cannot extensionalize all kinds of potentialities and this can be appraised in the case of the decay of radioactive atoms. To be more specific, radioactive atoms with the very same physical structure decay at different times. Moreover, scientists define radioactive atoms decay as a stochastic phenomenon since they can calculate just the half-life of the abovementioned atoms; and they can decay at any time even though they are physically identical. This leads us to think that the potentiality of decaying at a certain time, in this case, resides in the thing itself and not in its shared substructure with other atoms; thus, the modality here seems to be *de re.*

To clarify this, it should be taken into account an example of a radioactive atom, i.e., Carbon-14, and see whether other atoms alike in molecular structure behave all the same way. As considered previously, for Quine, the dispositional element of an object has to do with the linguistic form it is expressed and it could be eliminated by saying that it has a similar structure of something else that, say, breaks or dissolves in the same circumstance. The problem with radioactive atoms is that they are able to behave in different ways in similar circumstances. In other words, the probabilistic disposition of decaying raises the issue that two atoms can be alike in substructure but behave differently in the same circumstance.

As Salmon (2001 p. 212) points out regarding a radioactive isotope of carbon called Carbon-14:

> let us turn to an example that has a good chance of being irreducibly statistical. Its statistical character results not from our ignorance but from the physical features of the situation. Carbon-14, which is widely used by archaeologists and others to date remains of living materials, has a half-life of 5,730 years. This means that any given C^{14} atom has a probability of one-half of decaying in that period of time and a probability of three-quarters of decaying in 11,460 years. According to our best current theories, there is no further factor that determines which atom will decay and which will not.

According to this, it should be underlined two aspects:

a) Here Salmon (*Ibid.*) specifies that the phenomenon considered, i.e., the decay of Carbon-14, is fundamentally statistical and that it involves physical features of the event considered and does not deal with our ignorance of the experimental situation.

b) Salmon (*Ibid.*) stresses that *any* given Carbon-14 atom possesses the ½ probability of decaying after 5,730 years and the ¾ probability of decaying in 11,460 years.

Regarding a) it clarifies that in the case of radioactive decay our subjective degrees of belief on the decay of Carbon-14 play no role at all in the above mentioned physical situation. More on probability as degrees of belief will be considered at a later stage of the thesis. Regarding b), as underlined, Salmon (*Ibid.*) argues that *any* radioactive isotope of carbon (i.e., Carbon-14) have 50% of probability of decaying after 5,730 years; It has been stressed here that Salmon (*Ibid.*) refers to *any* Carbon-

14 atom and the property of these atoms of decaying probabilistically. Probability here seems to be more a dispositional character shared by all the Carbon-14 atoms. Indeed, in the case considered previously it is not just the claim that ½ of the Carbon-14 atoms, which have a similar structure, taken into account in the measurement process decay after 5,730 years. Indeed, radioactive atoms seem to exhibit a single-case kind of probability, that does not deal with the repeated observation of a phenomenon. Specifically, in the case mentioned by Salmon (2001), the probability of decaying at a certain time cannot be identified with the ratio of atoms that decay at a certain time. Indeed, in this case one should have a finite or infinite series of trials from which the probability of decaying is deducted. On the contrary, in the case taken into account, each Carbon-14 atom exhibits ½ probability of decaying after 5,730 years and the ¾ probability of decaying in 11,460 years. It seems that the Carbon-14 atoms have an embedded probabilistic aspect that derives from the physical aspects of the decaying. This is shown also by the fact that if one considers atoms of the same kind, thus, alike in molecular structure they still exhibit a different behaviour. More on radioactivity and the fact that the statistical claim only is insufficient to make sense of the decay of radioactive atoms will be said in Chapter III [B.6].

B.3. ***Probability and modal involvement***

Till now I considered Quine's attitude towards modality in logic and physics and even if his arguments on dispositions are closely related to the issue of probability, Quine does not clearly mention probability in 'Dispositions and Conditionals'. Indeed, he talks about probability in *From Stimulus to Science* (1995), where he underlines that probability in his preferred account is subjective. This means that Quine believes that probability expresses the degree of belief that a certain event occurs. Moreover, he thinks that "it is a quantitative refinement of a propositional attitude and admits a formulation *de dicto* with the help of quotation in the manner of other propositional attitudes" (Quine, 1995 p. 99). *Contra* Quine, Smokler in his article 'Three Grades of Probabilistic Involvement' (1977), argues that probability represents an unacceptable grade of modal involvement for extensionalists since it cannot be treated like *de dicto* modalities. To support his argument, Smokler (1977) considers the distinctions made by Quine among the grades of modal involvement in the paper 'Three Grades of

Modal Involvement' (1966) and applies them to probabilistic claims. For this reason, before talking deeper about Smokler's (1977) paper I will consider Quine's 'Three Grades of Modal Involvement' (1966).

B.3.1 ***Degrees of modal involvement***

In 'Three Grades of Modal Involvement' (1966), Quine firstly points out that, although he conducts his discussion on necessity, that is used just as a model. Indeed, "Whatever may be said about necessity may be said also, with easy and obvious adjustments, about the other modes" (Quine, 1966 p.156), i.e. for the other modal concepts. After this premise, Quine (1966) outlines the three grades of modal involvement:

1. The first degree occurs when necessity is taken into account as a property of a sentence. Moreover, 'Nec' in this case is intended as a predicate or a verb. In other words, the first grade of modal involvement occurs when the modal operator 'Nec' is attached to the name of a given sentence. Thus, everything one finds after 'Nec' is just an expression that refers to itself, the content of the sentence is not taken into account at all. For example "Nec 'Napoleon escaped from Elba'" (Quine, 1966 p.157) is a sentence of the first degree of modal involvement.
2. The second way of using 'nec' occurs when necessity represents a statement operator that can be attached to statements to form other statements. In this case, 'nec' is attached directly to the statement and not to the name of the sentence and it is rendered as "necessarily" (i.e. as an adverb). Quine provides a useful example when he says that the second degree of modal involvement occurs when one prefixes 'nec' to the actual content of a statement and not to its name (according to Quine's examples: "nec (Napoleon escaped from Elba)" expresses the second grade of modal involvement while, as just considered, "Nec 'Napoleon escaped from Elba'"represents the first one) (*Ibid.*). 'nec' is used in this way in propositional modal logic.
3. The third grade occurs when necessity operates subsententially in the scope of the quantifiers not outside of it. "Finally the third and gravest degree is

expression of necessity by a sentence operator. This is an extension of the second degree, and goes beyond it in allowing the attachment of ‘nec’ not only to statements but also to open sentences, such as ‘x>5’, preparatory to the ultimate attachment of quantifiers” (*Ibid.*).

For example, “(∃x)(nec(x > 5))” (1966 p.170) is a sentence that exemplifies the third grade of modal involvement. As clearly seen, quantification is involved in the third degree of modal involvement.

B.3.2 ***Acceptable and unacceptable degrees of modal involvement***

Quine (1966) clarifies that the third grade of modal involvement is unacceptable for extensionalists, thus should be refused. On the contrary, the first and the second grade of modal involvement can be extensionalized. To be more specific, sentences of the first grade of modal involvement preserve extensionality since ‘Nec’ is not referred to the content of the sentence. On the contrary, to transform second grade of modal involvement sentences into sentences of the first grade Quine uses quotation marks and turns the abovementioned sentences into extensional ones. For example: “nec (Napoleon escaped from Elba)” is transformed in “Nec ‘Napoleon escaped from Elba’”. What Quine stresses here is the semantical use of “nec (Napoleon escaped from Elba)”. Indeed, this type of modal involvement can be accepted in so far as ‘nec’ is interpreted as ‘Nec'. This process cannot be performed with sentences of the third grade of modal involvement, where the modal operator is applied to the content of a sentence that contains quantifiers, as I considered previously. In this case, issues with substitutivity (that occurs when that term is referentially transparent or purely referential can be substituted by any other term referring to the same object *salva veritate*, i.e. preserving the truth values of the statement taken into account) emerge and commitment to Aristotelian essentialism is inevitable. Quine believes that Aristotelian essentialism is undesirable due to the fact that he cannot accept the idea that all objects have some traits necessarily. Moreover, Aristotelian essentialism attributes to objects essential and accidental properties, as already considered, "independently of the language the thing is referred to [...] For Quine, it makes no sense to say, independently of a linguistic or conceptual system that 'X must be P'. All such declarations depend on the manner of referring to an object, not on the object itself" (Rasmussen, 1984 p. 316).

Furthermore, according to Quine, quantified modal logic leads to this form of essentialism which is undesirable also because *de re* modality is involved.

B.3.3 ***Probability in the scope of the third grade of modal involvement***

Having considered this, we turn our attention to Smokler's 'Three Grades of Probabilistic Involvement' (1977). In the above mentioned article Smokler (1977) wants to demonstrate that probability exemplifies the third grade of modal involvement. To do so, he argues that probability is not extensionalizable, this means that it cannot be reduced to sentences of the first grade of modal involvement. In other words, accepting probability would mean accepting *de re* modalities. To support his thesis, Smokler (*Ibid.*) employs the distinctions used by Quine in 'Three Grades of Modal Involvement' (1966) to distinguish the three degrees of modal involvement. So, Smokler's (1977) main aim is to demonstrate that probability is considered an unacceptable grade of modality and by the means of paraphrasing he highlights that probability exemplifies the third grade of modal involvement. Paraphrasing some probability statements, he demonstrates that in some of them (that express truths about the world) probability is *de re*, thus objective. Before doing this, Smokler (*Ibid.*) recalls Quine's (1966) treatment of the three degree of modal involvement underlining that while statement of the first degree of modal involvement "are expressed in a metalanguage whose object language is an extensional first-order language" (1977 p. 132), statements of the second and third degree of modal involvement make use of first-order intensional language (*Ibid.*); with the statements of the second degree that can be rendered extensional. Smokler (1977 pp. 130-131) underlines that

> Extensionalists measure their adversion to a language/theory by its degree of commitment to intensional entities. Statements of type (A) seemingly commit one only to inscriptions, while those of type (B) commit one to propositions. Even if the extensionalist does not paraphrase statements of the second grade of intensional involvement into statements of the first grade of intensional involvement, he is still committed to the existence of propositions. And these propositions may be reducible to sets of truth-values of the sentences which they express. On the other hand, statements of type (C)

involve a commitment to essential properties.[2]

This clarifies further the issues treated in the previous paragraph [B.3.2] and lays the foundation for Smokler's discussion. Indeed, to support the thesis that probability statements exemplify the third grade of modal involvement, Smokler (*Ibid.*) takes into account four statements as role models. Three out of four express objective probability, while the fourth one expresses subjective probability. And, according to Smokler (*Ibid.*), all the probability statements about the world are objective, which is in accordance with physics. On the contrary, the probability statement that expresses our beliefs about something is subjective. Quine does not distinguish between the two since, in this phase of his speculation, he believes that all the probability statements are subjective. Examples of probability statements that express truths about the world are "The probability of getting a head on a toss of this well-tested coin = 1⁄2" or "The probability of an alpha ray striking the area *A* of the target in experiment *E* = 0.3476" or "The probability that an American male of the professional classes who is alive at 35 being alive at 36 = *p* = 0.832" (Smokler, 1977 p.133). On the contrary, subjective probability statements are of the kind of "It is highly probable that Caesar crossed the Rubicon" (*Ibid*.). It is clear that the type of statements considered by Smokler (1977), except the fourth one, are often employed in physics and other scientific branches. Moreover, Smokler (*Ibid.*) underlines that the first three statements can be linguistically distinguished from the fourth and "The singular term 'the probability of' takes as an object a phrase denoting a specific or generic event in 1), 2), and 3): the probability statements in these cases is an identity statement, and a specific real number is identified as the probability of the specific or generic event. In 4), the term 'It is highly probable' takes as an object the name of a proposition; it is not an identity statement, and a comparative term 'highly' qualifies the ascription of probability to the object."[3] (*Ibid.*). Smokler (1977) underlines that the first three statements "are taken to be concerned with states of the world (objectivist theory of statistical probability) while 4) is taken to exhibit the logical or personalistic conception of probability" (1977 p.134) with objective mathematical probability that

2 For statements of type (A), Smokler (1977) intends statements of the first grade of modal involvement. Statements of type (B) represent the statements of the second degree of modal involvement and (C) statements, are the statements that exemplify the third grade of modal involvement.

3 Smokler (1977) numbers each statement with 1), 2), 3) and 4). Even if the numbering has not been retained here, it has been used the same order proposed by Smokler in quoting the statement.

can be assigned only to generic events and not to singular ones (*Ibid.*). After that, Smokler (1977 p.135) presents the logical forms of the statements considered above, highlighting that the first three statements are statements that express generic events, while for the fourth one probability is assigned to a singular event; in this latter case objective probability is ruled out. After that, Smokler (1977 p.135) relies on universal generalisation and determines the scope of the quantifier in the generalisations of the first three statements. Subsequently, Smokler (1977 pp.136-137) proposes two results and paraphrases both of them. By the means of paraphrase, Smokler (1977 p.137) notices that “a first-order language of comparative probability, sentences exemplifying quantification into probabilistic contexts are required to paraphrase typical probability statements”, here for typical probability statements, Smokler refers to statements that contains objective probability; thus, that express truths about the world are are commonly used in science.

The subsequent part of the article is devoted to find out whether the paraphrases proposed by Smokler (1977 pp.136-137) are in line with one of the available interpretations of probability to substantiate his claims. Smokler (1977 p. 137) takes into account the propensity theory highlighting that he defends the single-case propensity theory, which is supported by Fetzer amongst the others. More on the propensity view in general and the single-case one, will be said in Chapter II of this thesis, but, for now we just consider that according to the propensity view there is a relationship between some dispositional properties of entities and probabilities.

Smokler (1977 p.138) takes into account a paraphrase proposed by Fetzer, who adheres to the single-case propensity view, and compares it with his paraphrases of the probability statements he considered in the first part of the article. The paraphrase provided by Fetzer “for attributing probability to generic events, is a counterpart to the paraphrase of generic probability statements provided by me earlier in the paper. It involves quantification into a probability context.” Smokler (*Ibid.*) argues. A similar discussion is performed by Smokler in another article (1979) where he considers the same example of the alpha ray seen above. It is worthy to underline that Smokler (1979 p. 503) adds that Fetzer’s proposed logical form of the probability statement taken into account supports the idea that they are *de re* modal statements. To demonstrate this, Smokler (*Ibid.*) clarifies that attempts to interpret the logical formulations in a *de dicto* way would not preserve the meaning of the initial statements considered.

Therefore, relying on paraphrases of generic scientific statements, in which we find objective probability expressed, and on the impossibility of retaining the same meaning of the statements using a *de dicto* formulation Smokler (1977 and 1979) demonstrates that quantification occurs into probability contexts and that probability exemplifies the third grade of modal involvement. It is important to underline that the discussion relies on Smokler's adherence to the single-case propensity view. Interestingly, Smokler (*Ibid.*) underlines that we are still able to paraphrase our objective probability statements into pure frequentist (i.e., statistical) terms and in this case we are not committing to quantification into probability contexts; nonetheless he highlights the difficulties of the frequentist perspective that make it less desirable than the propensity view. In the context of this thesis, it is worthy to underline that the frequentist interpretation of probability runs into important problems and more on this, is spelled out in Chapter II. Plus, Quine seems to distance himself from the frequentist view proposing either subjective probability or the propensity view that is why we will focus our attention on propensities and subjective probability and propose discussions on this.

B.3.4 ***Where is the modal element of probability?***

The discussion till now focused on probability as a type of modality. The modal element of probability is well explained by Kattsoff (1937 pp.78-85), who analyses probability as a modality in logic.

> When we consider probability and modality closely we are struck by the fact that in the case of both identical terms are used to interpret their laws. And further that these terms seem to be interchangeable. A proposition said to be possible is also said to be probable; that which is universally true is said to be necessary. The only radical difference seems to be that in probability we have a continuum of probabilities, while in modality so far we have only finite, discrete possibles. (…) Mathematicians had, very early in their study of probabilities, stumbled across the happy thought of denoting probabilities by the numbers between 0 and 1, letting 0 = impossibility, 1 = necessity, and anything between these two = probable. This immediately offered all they needed. It allowed for the infinitude of degrees of probability (Kattsoff, 1937

pp. 79-80)

Moreover, Kattsoff (1937 p. 80) considers:

> In order now to substantiate the claim that modality and probability are identical, it will be necessary to show:
>
> > a) that the definition of propositional function in logic corresponds to the definition of probability.
> >
> > b) that modality implies probability and probability implies modality.
> >
> > c) that, as a consequence of (b), either there are an infinite number of modes, or else an infinite number of probable propositions are represented by only one modal proposition.

Here, for the purpose of the thesis it will be considered point b). In order to demonstrate that modality implies probability and that, in turn, probability implies modality, Kattsoff (1937 p. 83) examines the link between possibility and probability.

> That there is some connection between the possible and the probable, I believe no one will seriously doubt. In everyday discourse we frequently use the two as synonymous. (…) Now from a logical point of view there are three alternatives: (1) the probable is wider than the possible, i.e., there are things which have a probability but are not possible; (2) the possible is wider than the probable, i.e., that there are things possible that have no probability; (3) they are co-extensive.

Kattsoff (1937 pp. 83-84) demonstrates that both (1) and (2) are unable to define precisely the connection between possibility and probability. Therefore, Kattsoff (1937 p. 84) concludes that possibility and probability are co-extensive, applying to the same kinds of things or events.

Interestingly, the discussion of probability as a modality and its closeness with possibility could be linked with the question raised by Smokler (1977) regarding the third degree of modal involvement and his interpretation of probability as a problematic type of modality for Quine. Smokler (1977 p. 138) focuses his attention on the dispositional character upon which one needs to quantify to explain some experimental measurements. Regarding this, Chatti (2011), whose article ‘Extensionalism and Scientific Theory in Quine’s Philosophy’, is discussed and evaluated in the next lines, mentions both propensities (i.e., dispositions) and frequential probabilities. Regarding propensities Chatti (2011 p. 18) highlights that the metaphysically obscure status of propensities makes them unavailable for being extensionalized using Quine's method. Plus, Chatti (2011 pp.18-19) regarding frequential probabilities explains that:

> even this interpretation is not extensional in some cases. One of these is the so-called single case: it is the case where the coin is tossed only one time. In that case, extensionality fails for if we treat this single case extensionally we arrive to untenable results, as is shown by the following argument: with frequential probabilities, one considers the real tosses and frequencies and not the possible tosses as with logical probabilities. Because only real events are involved, substitution of coreferential events can be made. But if we consider the case where a coin is tossed only once, then this unique toss may be either a tail or a head. If it is a head, then ‘the next toss = the next head’ (since it is the same event) and ‘the probability for the next toss to be a head = the probability for the next head to be a head = 1’. If it is a tail, then ‘the next toss = the next tail’ and ‘the probability for the next toss to be a head = the probability for the next tail to be a head = 0’. This result is due to the substitution of ‘the next toss’ by ‘the next tail’ and by ‘the next head’ which is possible because, in both cases, it is the same event. But then we have two probabilities for the next toss to be a head, which are 1 or 0, and this is not admissible, since each event must have only one probability.

These remarks could be a useful addition to Smokler's (1977) reasoning regarding how probabilities in physics represent the third degree of modal involvement. Indeed, in addition to Fetzer's words mentioned by Smokler (1977), Chatti's (2011) explanation on why propensities and frequential probabilities cannot be extensionalised clarifies why they could be considered problematic for Quine.

B.3.5 ***Thoughts on Three Grades of Probabilistic Involvement***

According to the viewpoint pursued in this thesis, Smokler's argument (1977) is vital to start a critique of Quine's viewpoint on probability. Setting apart the agreement of this thesis with Smokler's treatment of probability as a third grade of modal involvement (*Ibid.*), it should be added that subjective probability plays a role in science even though its only role is related to scientists' way of conducting their experiments. In other words, scientists are often guided by their degrees of belief when they decide to perform an experiment rather than another one etc. Thus, we could conclude the role of subjective probability should be confined to every day scientists' practice. More on this could be an argument for future work while a complete discussion on subjective and objective probability will be performed in Chapter II that will ground the discussion that at least some objective probability claims are required in science.

Section C: ***Incomplete critiques***

In section C, there will be taken into account two papers that openly criticise Quine's approach to scientific practice and probability. It will be highlighted that both the accounts provide valuable insights on Quine's philosophy and represent a first stepping point to look critically at the Quinean philosophy in relation to science. Therefore, it will be argued that current efforts on Quine's philosophy in relation to QM probabilities need to be enriched to develop complete and exhaustive research on the theme. Section C.1 examines Hintikka's perspective (1997) on the role played by hypotheses in the scientific practice, highlighting that possible worlds play a non-negligible role in science as considered by Hintikka. Section C.2 takes into account Chatti's aforementioned critique of Quine (2011). This latter one concerns the idea that scientific language cannot be always extensionalised, hinting that some of the scientific modalities are *de re.* In section C.3, it will be argued that despite the important efforts in developing a critique of Quine's account of modality, more needs to be done especially in the case of QM probability that represents a real threat to the Quinean system.

C.1. ***Hintikka against the one-world assumption***

Hintikka offers an argument for the role of possible worlds in our scientific theories that is supported by examples from scientific practice itself. Indeed, he argues that scientific practice is undoubtedly based on entertaining modal hypotheses that help scientists to gain knowledge about our actual world. To be more specific, he argues,

> model theorists consider the actual world only as one of a multitude of

> possible worlds. What a scientist employing probabilistic or model-theoretical concepts is aiming at may very well be in the last analysis to describe and otherwise intellectually master our one and only actual world. But the scientist's means of doing so often involve conceptualisation that transcend the boundaries of this world. This happens for instance as soon as probabilistic concepts are employed, as they in fact are in much of the actual physical science. (Hintikka, 1997 p.459)

Hintikka believes that the one-world assumption, according to which "the only purpose of our [...] scientific discourse, is to represent things as they are in this one actual world of ours" (Hintikka, 1997 p.458), influences the whole Quinean perspective. But this assumption is at odds with the actual methods used by physicists to develop their theories about the world, as considered previously. Furthermore, I think that to complete Hintikka's reasoning on the theme, the role of models played in the majority of scientific branches should be investigated. Indeed, they are nothing but mathematical or visual artefacts used by scientists to understand how the real world is. In other words, we can say that scientists describe reality and draw conclusions aided by models that are approximations of the actual world. This means that scientists always rely on conceptualizations to depict reality. Among the above mentioned models, we can find probabilistic ones that are often employed to describe stochastic systems, while visual models are widely used in biology. For example, as additional evidence in support of Hintikka's argument, we could consider that engineers developed an electric model of the cell membrane. The cell membrane has a double lipidic layer made of an electrical insulator that separates the inside of the cell from the outside. To develop a visual model of the cell membrane, the abovementioned double lipidic layer has been represented by an electrical condenser. Visual models of this condenser are commonly used by biologists. An analysis on the above mentioned theme is conducted by Brosseau and Sabri in 'Resistor–capacitor modeling of the cell membrane: A multiphysics analysis' (2021). This means that biologists and all the other scientists formulate theories and reach the truths about our world aided by models that could be alternative worlds or models intended as fictions. These aspects fall outside of the scope of this thesis but represent interesting research insights for future work.

C.2 ***Chatti on the issue of the scientific language***

Chatti (2011) argues that scientific language is intensional and cannot be extensionalised. In other words, science uses intensional concepts and its truths and principles cannot always be translatable into pure extensional logic. Chatti asks,

> Is science as it stands totally free of modalities? It does not seem to be so if we consider some scientific claims. Thus Werner Heisenberg expresses the uncertainty relations in the following way: ‘It has turned out that it is in principle impossible to know, to measure the position and velocity of a piece of matter with arbitrary accuracy’ (Quoted in Hilgervood and Uffink 2006). This sentence contains the word ‘impossible’ which is modal, and this shows that scientific discourse is not as Quine says entirely extensional. How could Quine account for that? He could say for instance that these modalities are *de dicto* and so extensionalizable in the way he himself uses in *The Ways of Paradox* and elsewhere. (Chatti, 2011 p. 12).

Regarding this, the methods used by Quine to extensionalize intensional contexts involve paraphrasing and what Chatti calls ‘spelling’, which involves interpreting a given sentence as a sequence of letters, this avoids substitution and guarantees extensionality by dissolving the term or statement taken into account (Chatti, 2011 p. 12-13 and 17). Thus, ‘spelling’ operates by vanishing the sentences considered, and this enables avoiding substitutivity problems, as Chatti clarifies (2011 p.12). Thus, Chatti says that Quine's method leads us to write Heisenberg's principle in this way

> ‘Measuring the position and the velocity of a piece of matter with arbitrary accuracy’ is impossible. [...] Then by using Quine’s method of spelling, one could interpret the whole sentence as a sequence of letters, which makes the substitution superfluous and extensionalizes the context. But this could not work in this case for the impossibility here is not a feature of the sentence itself but of the measurements. Heisenberg’s principle, on the contrary, does not say that the *sentence* ‘measuring the position and the velocity of a ...’ is impossible; rather, the impossible thing is to determine the measurements themselves since one cannot give simultaneously the numerical values of both the velocity and the momentum. It is these quantities that are impossible

> to fix simultaneously. As Jan Hilgevoord and Jos Uffink say, ‘a measurement does not only serve to give meaning to a quantity, it *creates* a particular value for this quantity. This may be called the “measurement = creation” principle. It is an ontological principle, for it states what is physically real’ (Hilgevoord and Uffink 2006). The uncertainty is thus real, it is not only epistemic. The impossibility seems then more *de re* than *de dicto.* (Chatti, 2011 p.13).

Thus, we can appraise Chatti (*Ibid.*) highlights that modality is *de re* in the case mentioned above, thus, could be considered a problematic degree of modal involvement for Quine. Moreover, Chatti (*Ibid.*) also specifies that given the impossibility of extensionalizing *de re* modalities it appears that QM involves intensionality and it is not extensional as other fields of physics and first-order logic would not be the adequate language to express the truths of QM.

Chatti (2011 p. 4) also talks about probability and extensionality, saying that:

> Probabilities are not extensional in this sense as is shown by Christopher Hookway in the following example: ‘The probability that the reaction will occur is *n*’ (Hookway 1988, 106). In this sentence, substitution does not preserve the truth value of the whole, for the probability may change when we substitute to ‘the reaction will occur’ another true sentence. The context is thus intensional.

Moreover, according to Chatti (2011 p. 13) naturalism and extensionalism could run into incompatibility with probability playing an important role *contra* extensionalism. Chatti's speculations (2011) represent the starting point for this thesis that aims to develop these issues, expanding them, emphasising that alternative ways of dealing with the problem and preserving both naturalism and extensionalism are unavailable for Quine.

C.3 ***The need to examine Quine's account more closely***

Following these speculations, it seems that both scientific methodology and language need modality. Chatti's (2011) account is surely the most accurate one when we consider the relationship between Quine's account on modality and possible worlds in physics. But it is not complete as it provides important insights that should be enriched. Plus, Chatti's account is not devoted to the same basic idea pursued in this work. Chatti is persuaded that Quine's perspective fails because it is too radical since he refuses to accept that physical theories do not admit the same degree of extensionality, which depends on the object considered. This idea could be refuted since even if classical physics could be considered at a first glance extensional since the wavelength of macroscopic bodies is very tiny, instead it is not given the fact that QM accounts for the behaviour of fundamental particles. Thus, it also grounds classical mechanics. Therefore, at least for now, QM is considered the most fundamental branch in physics. Indeed, every large body is made of microscopic entities like electrons and all the bodies have a wave function. In other words, all the bodies behave both as objects and as waves. The wave function of each object is inversely proportional to its mass. That is why classical mechanics is still a good way to describe macroscopic phenomena, however, QM is more basic. This means that Quine’s flaws do not lie only in his radical approach towards modality in science but the rejection of the intrinsic nature of the world, which could be modally problematic. The above mentioned modal, probabilistic nature, in turn, is expressed by our best scientific theories. Moreover, probability is deeply involved in physics and science, in general. Physicists' method is a probabilistic one, probability statements are regularly involved in physics and there are strong reasons to think that probability is objective. That is why, in this work, it is supported by the idea that Quine's account runs into problems and that difficulties arise when it is attempted to save it.

Amongst the objections to Quine considered till now, Hintikka and Chatti's show general attempts that have been made to criticise the extensional aspect of the Quinean philosophy, pointing to a range of examples where an extensional interpretation looks difficult to maintain. My focus in this thesis will be on the failure of Quine’s anti-modal extensionalism in dealing particularly with probabilities in science, and especially in quantum mechanics. Thus, Smokler's argument (1977) *against* Quine represents the ground of the reasoning that will be pursued in this work. Specifically, it will be considered the issue of objective probability in science and whether science needs objective probabilities that cannot be rendered in an extensional way as considered by Smokler (1977).

Conclusion

This chapter aimed to provide the basis for further discussion to be pursued in the next chapters of the thesis, shedding light on Quine's perspective on probability and the philosophical cornerstones of interest for this work, and how these aspects relate to probability in QM. Section A looked at probability in QM, emphasising the probabilistic nature of the wave function. Section B was aimed at clarifying Quine's philosophical cornerstones and his viewpoint on probability and modality, while section C focused on the incomplete critiques of Quine touching on speculations close to the one pursued in this thesis, to the effect that Quine's commitment to trusting science is likely to undermine his anti-modalist extensionalism. In relation to these critiques, this chapter also specified that the research carried out in this thesis aims to extend the scope of earlier critiques scholars pursued on probability and QM in the Quinean philosophy, providing a fresh and more thorough view on the issue.

While section A, looks at the issue of probability in the field of QM exploring just a few characters of it to introduce the reader to the arguments of this thesis in a gentle way, a fuller and more detailed treatment of QM and the role of probability in the above mentioned field of knowledge is pursued in Chapter III. Thus, in section A, only a few aspects of QM are taken into account, with few lines dedicated to QM development. Moreover, the Schrödinger equation, the Double Slit Experiment and the reason why Newtonian Mechanics are still successful have been considered with hints about the concept of wave function, waves and probabilistic nature [A.1]. After that, the issue of probability in QM and the probabilistic aspect of the wavefunction is briefly discussed. Taking into consideration Griffiths' (1995) *Introduction to Quantum Mechanics*, it has been evaluated that the transition between determinism and indeterminism occurred with QM. Also, it has been highlighted that probability in QM is a peculiar concept that would seem to imply a probabilistic aspect of nature [A.2].

In order to navigate the Quinean philosophy, section B has been dedicated to the major aspects of interest we retrieve in the Quinean philosophy for this thesis. Thus, some of Quine's philosophical cornerstones have been taken into account and deepened.

In particular subsection B.1, focuses on extensionality and intensionality underlining that Quine favours the first of the two and fights the second one, criticising those committed to intensionality. Subsequently, the thesis looks at Quine's naturalism and the ontology he commits to. Indeed, it is underlined that naturalism and the Quinean ontology are deeply and strictly interlinked with scientific theories that play a crucial role [B.1.1-B.1.2]. Subsection B.2, is devoted to look at what Quine said about modality and probability in physics. Hence, the issue of quantification and opaque contexts has been clarified, specifying that Quine opposes quantification into intensional/opaque contexts [B.2.1]. Also, research has been performed on modality in physics in the Quinean speculation and it has been established that Quine treats physical modalities on a par with logical modalities [B.2.2]. After that, the chapter considers Quine's treatment of dispositions comparing the Quinean treatment of dispositions focused on extensionalising dispositional terms with the kind of disposition displayed by radioactive atoms and the phenomenon of radioactive atoms' decay, where the disposition of radioactive atoms to collapse after a certain amount of time is seen as something fundamental that cannot be extensionalise [B.2.3-B.2.4]. In subsection B.3, it has been considered the theme of probability in relation to the three degrees of modal involvement proposed by Quine (1966). The three grades of modal involvement are described and attention is put on the third degree of modal involvement deemed to be problematic for Quine since it cannot be extensionalised with the devices used by Quine for the purpose [B.3.1-B.3.2]. Subsequently, arguments in favour of probability as falling in the third grade of modal involvement are being taken into account with the three degrees of modal involvement put in relation to probability. In particular, after having considered Smokler's thoughts (1977) on some particular probabilistic statements that exemplify a third grade of modal involvement [B.3.3], it has been established where and what is the modal element of probability. Specifically, it has been clarified that probability and possibility seem to be co-extensive finally shedding light on the modal element of probability [B.3.4]. Furthermore, in this piece of this work, Smokler's claims (1977) on probability as a problematic degree of modal involvement for Quine have been supported by Chatti's words (2011) on propensities and frequential probability [B.3.4]. In B.3.5, few thoughts are shared on the theme of probability as a problematic degree of modal involvement.

Finally, subsection C, is dedicated to consider the wider role of modality in science.

Moreover, there have been taken into account two critiques to Quine’s treatment of modality and probability in science that served as the stepping point to detect the need to do more in this field of the Quinean philosophy and further the discussion on probability in the Quinean speculation in relation to QM. In subsection C.1, the crucial importance of hypotheses and conceptualizations in science and scientific models has been taken into account while section C.2, has been dedicated to Chatti's (2011) rejection of Quine's radical approach toward extensionality in science. Specifically, it has been underlined that Chatti’s article (2011) represents useful and important food for thoughts and that it provides useful hints and a basis for deeper discussions on Quine’s extensionalism, naturalism and probability. Plus, it has also been clarified that while Chatti (2011) believes that the main issue with Quine is the profound radicality towards extensionality, this thesis looks at the failure of Quine’s anti-modal extensionalism in dealing particularly with probabilities in physics, and specifically in QM and that attempts to save it fail [C.3]. Therefore, the chapter has been concluded by clarifying that even though critiques to Quine's perspective represent a stepping point towards a more mature understanding of the Quinean philosophy, more is needed. For this reason, this work delves into the above mentioned issues providing its contribution to debates on the Quinean philosophical perspective.

Chapter II: Quine and the theories of probability

In this chapter, I claim that major philosophical theories of probability are unable to offer a valid way to combine Quine's extensionalism and naturalism with the role of probability in QM. This chapter will also serve as a foundation for the next chapters, where variations of the “traditional” theories of probability will be offered with the aim of finding a potential solution to the issue represented by QM probabilities in Quine's philosophy. This chapter features three sections. In section A, I outline the account of probability in physics offered by Quine himself. In particular, I highlight that in the first instance subjective probability is preferred by Quine while later a propensity view of probability is advanced. In section B, I clarify the concepts of epistemic, subjective, and physical probability. This section represents the ground for section C, where I offer conceptual clarifications about the interpretations of probability in philosophy and their limitations. I present the major arguments against each of them and they are seen in the light of Quinean philosophy. I adopt a twofold approach. On the one hand, the discussion relies on the conceptual clarifications of the above interpretations of probability, on the other hand, it is highlighted that QM probabilities cannot be properly accounted for with the “traditional” interpretations of probability in a Quinean naturalist light.

Section A: ***Quine's confessions***

In section A, I explore Quine's perspective on probability as presented in his later works . While in Chapter I, I focused on Quine's naturalist perspective and rejection of modality taking into account the line of thought he followed the majority of his life, in this part of Chapter II I focus on Quine's approach to probability only. In A.1, I briefly present Quine's preferred subjectivist account of probability. In A.2, I examine Quine's abandonment of subjective probability in favour of the propensity view for dealing with probabilities in quantum mechanics. Two main aspects are highlighted: the first one regards the fact that the late Quine changed his conception of probability due to QM and the second one, is Quine's main focus, that is extensionality (which is maintained in spite of his brand new propensity view).

A.1 ***Quine's subjective probability***

Quine's perspective on probability is in accordance with his perspective on modality, as highlighted in previous passages of this work. Indeed, Quine particularly tends to favour subjective probability. For this reason, in *From Stimulus to Science* (1995, p. 99) he underlines that probability is nothing but degree of belief. In other words, according to Quine, our probability claims express our degree of confidence in the occurrence of a certain outcome. Among the scholars who adhere to this perspective there is Bruno de Finetti, who shaped the subjectivist perspective on probability and greatly contributed to formulating the subjectivist theory, determining its major aspects. The reason for introducing de Finetti here is to make a bridge between this chapter and Chapter V where it is explained that de Finetti's theories have a non negligible importance for Quantum Bayesianism (which will be taken into account properly in Chapter V).

One of the few places where Quine talks about probability is *From Stimulus to Science* (1995 p. 50 and 99), where he says:

> The central concern of statistical theory is probability and subjective probability is degree of belief. The recent study of subjective probability by Brian Skyrms and Karel Lambert has an explicitly epistemological orientation. [...] Subjective probability is degree of belief. It dominates the normative side of naturalized epistemology, as noted at the end of Chapter IV. It is a quantitative refinement of a propositional attitude and admits a formulation de dicto with the help of quotation in the manner of other propositional attitude.

As seen in this quote, Quine's discussion is about the interpretation of probability in the statistical theory. Indeed, this line of thought seems to have a major drawback: it does not appear to be coherent with QM as confirmed by the later works of Quine (2008). That is, it is typically assumed that a subjective account of probability is unsuitable for dealing with probabilities in QM (though as we will see in Chapter V, QBism challenges this orthodoxy).

A.2 ***Extensional propensities***

As Quine notices, in the paper 'Pressing Extensionality' included in *Confessions of a*

Confirmed Extensionalist and Other Essays (2008, p. 175), adherence to the subjectivist account of probability would rule out the entire field of QM. Obviously, this would be incoherent within a Quinean framework, as QM is a well confirmed theory of physics and according to Quine's naturalism we ought to believe that our best scientific theories are true (at least until something better comes along). Therefore, Quine decides to remain open to the propensity viewpoint. Indeed, he suggests that the propensity perspective would be a viable way to define probability but still in an extensional light as made clear in *Confessions of a Confirmed Extensionalist and Other Essays* (*Ibid.*). Unfortunately, Quine does not deepen this point further. This means that he does not explain in a clear way how one could settle for propensities and preserve extensionality at the same time. This is something to think about in order to have not only a clearer picture of Quine's account but also to attempt to preserve a coherent Quinean framework by proposing alternative paths. Considering this, viable options for Quine to preserve both extensionalism and naturalism are examined in the next chapters.

Section B: ***Physical, epistemic and subjective probability***

In section B, I analyse the treatment of epistemic and physical probability. This part of the Chapter is about the differences between the two above mentioned viewpoints on probability, highlighting that Quine favours physical probability instead of the epistemic one. To understand this, I underline that there are different categories of probabilities. In B.1, I take into account the difference between subjective and objective probability, highlighting that knowledge plays a vital role in the case of subjective probabilities. In B.2, I add to Popper's distinction between subjective and objective probabilities the epistemic ones, highlighting the main features of the three categories of probabilities. In section B.3, I summarise the various treatments of probability that Quine takes into account: objective, subjective probability and probability in logic. I highlight that in the case of probability in QM, Quine favours an objective account of probability comparing it with the logical treatment of probability he makes in 'Reference and Modality' in *From a Logical Point of View* (1980) and 'Dispositions and Conditionals' in *Word and Object* (1960).

B.1 ***Popper's subjective and objective probability theories***

Interpretations of probability can be sorted out and be included in a specific category. Popper differentiates interpretations of probability in two classes: subjective interpretations and objectivist ones, saying:

> I have divided these interpretations into two main classes—the subjective and the objective interpretations. The various subjective interpretations have all one thing in common: probability theory is regarded as a means of dealing with the *incompleteness of our knowledge* (Popper, 1959 p.25).

Thus, underlining that subjectivist interpretation of probability has something to do with humans' insights on events, Popper (*Ibid.*) also believes that the objectivist interpretations of probability explain probability as something that can “be objectively *tested,* by means of statistical tests. These tests consist in sequences of experiments”. In other words, Popper's view of objectivist interpretations of probability deals with experiments and thus science, since statistical tests come into place to define or, more precisely, measure probability.

B.2 ***Physical probability, the epistemic and subjective one***

Mellor (2005, p. 8-9) extends the scope of Popper’s perspective identifying three types of probability: physical probability (identified as chance), subjective probability (also known as credence according to Mellor) and epistemic probability. Specifically, Mellor (*Ibid.*) states:

> *Chances* are real features of the world. (…) Chances are what they are whether or not we ever conceive of or know about them, and so they are neither relative to evidence nor mere matters of opinion, with no opinion any better than any other.
>
> *Epistemic probabilities* seem not to be real features of the world in this sense. They only measure how far evidence confirms or disconfirms hypotheses about the world (...) But they are not mere matters of opinion: whether, and to what extent, evidence counts for or against a hypothesis looks like an objective matter.
>
> *Credences* measure how strongly we believe propositions (…) They are

features of the people whose credences they are rather than features of what the credences are about.

To clarify, only physical probability is entirely objective. And, according to Hájek (2019, p. 11) in the case of physical probability, probability depends on how the world is and it is independent from available evidence and agents' beliefs. In the scope of physical probability fall frequentism, propensity view and Lewis' Best System account of laws of nature (*Ibid.*). For all of these interpretations of probability, agents' credences are not a matter of interest. While, in the case of frequentism, probability is defined in terms of relative frequencies, in the case of the propensity interpretation, probability is identified in terms of propensities; namely dispositions (Hájek, 2019). Plus, according to the Best System account, the laws of nature that are probabilistic, determine the chances that represent the probabilities (Hájek 2019, p. 57). More on the Best System account of laws of nature will be said in Chapter IV.

On the other hand, epistemological probability is the type of probability assumed by the classical account of probability and the logical one as noted by Hájek (2019, p.11). In the case of classical probability, this latter one is assigned in the case of equally possible evidence or in the absence of any evidence and is designated as a "fraction of the total number of possibilities in which the event occurs" (Hájek, 2019 p. 12). In other words, classical probability is considered in terms of rates of favourite outcomes over equally possible outcomes (*Ibid.*). While in the case of logical probability, probability is still determined by considering the entire space of possibilities but some possibilities can have an heavier weight than others and probabilities can be appraised even if we do not have equally possible evidences; thus, when evidence is not "symmetrically balanced" (Hájek, 2019 pp. 19-20). Evidence plays a pivotal role in the case of epistemic probabilities differently from objective probabilities, where probability is not subordinated to evidence.

Finally, subjective probability is linked to beliefs. Indeed, agents' degrees of belief in a certain outcome play a crucial role to determine probability. Hájek (2019 p. 29) highlights that

> According to the *subjective* (or *personalist* or *Bayesian*) interpretation, probabilities are degrees of confidence, or credences, or partial beliefs of suitable agents. Thus, we really have *many* interpretations of probability

> here— as many as there are suitable agents. (…) suitable agents must be, in a strong sense, *rational* (…) A rational agent is required to be logically consistent, now taken in a broad sense.

Therefore, in the case of subjective probability it is pivotal to have a rational agent and her degrees of belief on an event to determine the probability of the occurrence of the event considered.

B.3 ***Quine's probability: physical, epistemic or subjective?***

The greatest part of Quine's work on probability is influenced by his attitude towards modality, with probability treated as a *de dicto* modality that needs to be extensionalized with the help of quotation marks (Quine, 1995 p. 99). And, there is no exception for modality in physics. Indeed, physical modalities are treated in the same way as logical modality. To be more specific, the problem with physical modalities concerns again the language used to express these modalities, with the language with which physical modalities are expressed that needs to be extensionalised (Quine, 1980). This led to the consideration that probability as a type of logical modality permeates the greatest part of Quine's work combined with the idea that probability is subjective degree of belief (Quine, 1995 p. 99). This system is changed by Quine with QM, for he seems to favour the propensity view (2008). Therefore, Quine's rejection of subjective probability is demonstrated in the case of quantum probabilities. Indeed, even though extensionality still remains crucial, the subjectivist interpretation of probability is dropped in favour of objective probability.

Section C: ***The major interpretations of probability***

In section C, I delve into the major interpretations of probability, mentioning the main characteristics of the above mentioned interpretations and their drawbacks. In section C.1, I take into account the subjectivist interpretation of probability. Subjective probability has been Quine's favourite for the majority of his philosophical career. In this section, I examine subjective probability's key features and I pull out the general characteristics that make it the most attractive perspective for Quine in the first part of his philosophical speculation. I clarify that an attempt to save subjective probability in a QM framework is performed in Chapter V. After that, in section C.2, I analyse frequentism. Being both an extensional and objectivist viewpoint on probability, frequentism represents a point of contact between the early and the late Quine and also a way of preserving extensionalism. But, it is demonstrated that the major issues of single-case probabilities undermine the possibility of interpreting quantum mechanical probabilities as frequencies in the Quinean philosophy. Then, in section C.3, I focus my attention on the propensity view and I underline that, despite Quine's assumption to the contrary, it is not extensional in its original formulation. Therefore, I argue that it is not in line with Quine's ambition to develop a fully extensional philosophical system. Finally, in C.3.3, I perform a discussion on Popper's propensities and *potentiae* in Aristotle's philosophy and link this chapter with the themes treated in Chapter III and introduce Aristotle's potentialities.

C.1 ***Bayesian probability (also known as subjective probability)***

Giving a deep account of subjective probability represents the foundation of a deep understanding of Quine's choice to describe probability in subjectivist terms. As noticed previously in this work, subjective probability is understood as degrees of belief for Quine. This idea recalls the one underlying the Bayesian, i.e. subjectivist account of probability. The next lines of this work are devoted to outlining this perspective on probability. Uffink (2011) starts his history of subjective probability taking into account one of the major subjectivists of all time, namely Jacob Bernoulli. Indeed, according to Uffink (*Ibid.*), Bernoulli was the first thinker to define subjective probability in a quantitative way, and thus, the first to describe probability in modern terms. In order to create an account of probability, Bernoulli takes into consideration the concept of subjective certainty, defining probability as the degree of subjective certainty:

> He emphasizes that probability does not reside in the facts or events that we assign probability to. Rather, probability assignments represent an epistemic judgement. The assignments or evaluation of probabilities is a human endeavor, and this is what constitutes the art of conjecturing. Bernoulli also emphasises that a probability assignment to a given event may differ from

> person to person, depending on what information they possess. (…) For Bernoulli, probability is epistemic, it refers to human knowledge, human ignorance and expectation, and probability assignments may differ from one person to the next, depending on what information they possess. It is not a matter of physics, or objective fact (Uffink, 2011).

Uffink (2011) underlines also that Bernoulli's approach falls within the classical approaches to probability where subjective probability is taken into account because it is linked to states of humans' minds but also objective probability comes into play when all the rational minds possess the same knowledge and thus, reach the same assignment of probability. Moreover, Bernoulli distinguishes between two different methods of assigning probability. The first one is *a priori*, while the second one is an *a posteriori* method. The a priori approach is based on the very infamous Principle of Insufficient Reason. Dubs (1942, p.123) spells out the principle saying that it "asserts that where we do not have sufficient reason to regard one possible case as more probable than another, we may treat them as equally probable". In other words, the above mentioned principle states that in a collection of events, if we are ignorant as to which events are more probable than other events, all the events considered will be treated as equally likely. Justifying the Principle of Insufficient Reason is hard to do within classical probability. Specifically regarding the Principle of Insufficient Reason, Dotterer (1941 p. 297) starting from the definition of Laplace of probability, which is "the ratio of "favorable" cases to possible cases", takes into account the notion of the equal probability of the possible events or cases. Indeed, the Laplacian definition presupposes the concept of equal probability and at a first sight it seems that grounding the definition of probability on the idea of equal probability leads to a circular argument (Dotterer, *Ibid.*). Plus, Dotterer (*Ibid.*) underlines that it is at least very difficult for us to establish that an event is effectively no more probable and no less probable than another one. The Principle of Indifference or the Principle of Insufficient Reason arise to account for situations where equal probability occurs thus, according to the above mentioned principle, we need to consider two events as equally probable if we do not possess sufficient reason to establish that one possible event is more probable than another one (*Ibid.*). The issues related to the Principle of Indifference are linked to some contradictory results evaluated by scholars. In particular, Dotterer (1941) takes into account various cases proposed by other scholars where the Principle of Indifference may be deemed to be problematic. Specifically, one of the arguments considered by Dotterer (1941) takes into account the cases of the applicability of the above mentioned principle to the inhabitants of other planets. Therefore, Dotterer (1941 p. 298) reports:

> Professor Cohen, however (Reason and Nature, p. 134) presents an example, also relating to the inhabitants of Mars, in which, as he works it out, the principle of insufficient reason does lead to obviously contradictory results. The argument runs as follows: "Suppose that we know nothing at all about the possibility of life on Mars. The probability of there being no cat is ½ and the same for a snake, a bee, or any other animal. If then I ask for the probability of there being no cat, no snake, and no bee on Mars, I get the fraction ⅛ and the more animals I add the smaller the value of the fraction, so that the probability of there being no animal at all on Mars can be made negligibly small. I can thus on the basis of complete ignorance prove beyond a reasonable doubt that there is life on Mars".

We considered here just one example amongst the various ones to have little grasp on the issue, which will not be treated in-depth here since it is not the theme of this thesis.

Turning to the a posteriori method, this involves frequency with probability assigned on the basis of observed frequencies in analogous cases (Uffink, 2011). For example, to establish the probability that a storm will arrive in a certain area in a determined period of the year, one should look at a similar case in the past. In that way he or she would be able to determine how frequent are storms in that area in a given period of the year and can hypothesise how likely is the appearance of a storm in the same conditions. According to Bernoulli if we augment the number of observations, we are able to reinforce the degree of certainty of an outcome (Uffink, 2011).

A priori and a posteriori methods can inform individuals' assignments of initial degrees of belief (their so-called 'priors'), but the cornerstone of the subjectivist perspective is Bayes' theorem. This theorem explains how human beings should update their beliefs in the light of a new piece of evidence (Hájek, 2019 p. 37). In his article on the Bayes Theorem, Joyce (2021), introduces the above mentioned theorem saying that it is about "The probability of a hypothesis *H* conditional on a given body of data *E* is the ratio of the unconditional probability of the conjunction of the hypothesis with the data to the unconditional probability of the data alone".

Bayes' rule appears as presented below by Joyce (2021):

$$\mathbf{P}_E(H) = [\mathbf{P}(H)/\mathbf{P}(E)]\ \mathbf{P}_H(E)$$

In this mathematical theorem, there is a relation between "the "direct" probability of a hypothesis conditional on a given body of data, **P***E*(*H*), to the "inverse" probability of the data conditional on the hypothesis, **P***H*(*E*)" (*Ibid.*). In order to clarify the terms considered above, Joyce (2021) tells us that **P***H*(*E*) represents the "likelihood" of *H* on *E* and it "expresses the degree to which the hypothesis *predicts* the data given the background information codified in the probability **P**" (*Ibid.*). Where H stands for the hypothesis and E as the *corpus* of data, which constitute evidence (*Ibid.*).

While Bernoulli's view provides a useful insight on the early start of subjective probability and Bayes developed the theorem named after him that lay the foundation for the subjectivist interpretation of probability, the contemporary interpretation of subjective probability sees this latter one as subjective degrees of belief. Hájek (2019 p. 29) clarifies:

> According to the *subjective* (or *personalist* or *Bayesian*) interpretation, probabilities are degrees of confidence, or credences, or partial beliefs of suitable agents. Thus, we really have *many* interpretations of probability here — as many as there are suitable agents. What makes an agent suitable? What we might call *unconstrained subjectivism* places no constraints on the agents — anyone goes, and hence anything goes. (…) More promising, however, is the thought that the suitable agents must be, in a strong sense, *rational*. Following Ramsey, various subjectivists have wanted to assimilate

probability to logic by portraying probability as “the logic of partial belief” (1926; 1990, 53 and 55). A rational agent is required to be logically consistent, now taken in a broad sense. These subjectivists argue that this implies that the agent obeys the axioms of probability (although perhaps with only finite additivity), and that subjectivism is thus (to this extent) admissible.

From 1920 onwards the subjectivist interpretation of probability is resurging with the main and only requirement that makes a belief rational is coherence as explains Uffink (2011). In other words, a rational agent cannot consider bets that always lose as acceptable ones (i.e., the so-called Dutch Book) (Uffink, 2011). A “*Dutch book* is a series of bets bought and sold at prices that collectively guarantee loss, however the world turns out” (Hájek, 2019, p. 30). Thus, according to Hájek (2019 p. 31) the Dutch Book argument supports the idea that rationality involves that one’s credences have to obey the rules of the Probability Calculus. The Rules of Probability Calculus are the Restricted Conjunction Rule, which calculates the probability of two events that happen together despite being the two events independent of each other, General Conjunction Rule (which is used to calculate the probability of two events that happen together whether or not they depend on each other), Restricted Disjunction Rule (this rule is used to determine the probability of either of two events happening when they excludes mutually), General Disjunction Rule, used to establish the probability of either of two events whether or not they excludes mutually, and The Negation Rule (which is used to calculate the probability of a given event when the probability of the non-occurrence of the event considered is either easy to determine or already known). As it can be proved that if one’s degrees of belief don’t satisfy the rules of probability then a Dutch book is possible.

The list of the rules of Probability Calculus have just been mentioned here since they provide an interesting addition to this work. Unfortunately, not being the main theme of this thesis, it will not be given a fuller and deeper treatment of them.

C.1.1 ***More on subjective probability and its revival in Quantum Bayesianism (QBism)***

To support the idea that probability should be interpreted as the degree of confidence in an outcome, subjectivists opt for grounding their reasoning on mathematical rules to guarantee certainty. For example, Ramsey and de Finetti combine humans' degrees of belief (which derive from mental states) with mathematics and this results in the idea that degrees of confidence and human's betting behaviour are chained (Galavotti, 1991). In this way, subjectivists are able to assign a number to the degree of confidence. To do so, they use betting rates and discriminate against rational and irrational betting approaches. According to the subjectivist interpretation of probability coherent betting approaches satisfy the laws of probability calculus. This means that a betting strategy is called rational when it is based on coherent sets of beliefs. In a nutshell, a strategy is rational when it does not guarantee that one loses money, whatever the outcome of the event one is betting on. It can be proved that sure-loss contracts can be made based on an individual's degrees of belief just in case those degrees of belief fail to satisfy the laws of probability. Thus, a set of personal beliefs is coherent if it satisfies the mathematical rules of the theory of probability, according to subjectivists. Indeed, no rational human being would adhere to a sure-loss contract, namely a contract that guarantees a waste of money (Dutch Book argument).

Subjective probability has been incorporated in a novel interpretation of QM that goes under the name of Quantum Bayesianism (also called QBism). In attempting to save Quine's subjective probability, QBism is taken into account in this work. Indeed, QBists rely heavily on de Finetti's personalism and produced a new way of interpreting QM free of problematic modalities. A deep treatment of QBism is given in Chapter V, where all the drawbacks of the viewpoint will be highlighted to demonstrate that a subjectivist interpretation of QM probability cannot be maintained in Quine's philosophy, and that aside from QBism proponents, most physicists and philosophers assume that the probabilities in QM cannot be accounted for from a subjectivist perspective.

C.2 ***Turning to objective probability***

The propensity view of probability and frequentism fall in the scope of the objectivist interpretations of probability as considered above. The frequentist account of probability is considered in the first instance. Later on in the work I pay attention to the propensity perspective, which has been developed to make sense of a few issues generated by frequentism. Uffink, in his article 'Subjective Probability and Statistical Physics' (2011) mentions a brief history of frequentism, which I examine in the next lines. Frequentism was first developed around 1830, when a number of studies on some social phenomena like crimes, suicides, marriages were conducted (*Ibid.*). And for the first time, scholars thought that the abovementioned social phenomena were governed by objective statistical laws that had nothing to do with personal subjectivist beliefs or credences (*Ibid.*). This viewpoint became popular, thus a number of philosophers developed their view on the theme. Venn, amongst others, is considered one of the originators of the frequentist perspective (*Ibid.*). Furthermore, the frequentist perspective received great support and has been warmly welcomed by a number of scientists (*Ibid.*). There is a non-negligible link between frequentism and statistical physics that was developed in the same period with the eminent statistical physicists that adopted an objectivist account of probability (*Ibid.*). Uffink (2011 p. 38) points out that according to Maxwell

> the probability of a molecule to have its velocity between certain limits is the relative number of molecules in the gas having this velocity, i.e. as an actual and objective fact about the dynamical state of the gas, without any reference to a reasonable man's mind

A similar position on the objectivist interpretation of probability is shared by Boltzmann, as noted by Uffink (2011). Indeed, however, Boltzmann is unclear on his own interpretation of probability (since he uses a variety of probability notions in his writings, so there is no unique perspective on probability in Boltzmann's line of thought) (Uffink, 2011 p. 40). Nevertheless, he is sure that probability is an objective quantity (*Ibid.*). The majority of the notions used by Boltzmann on probability derive from dynamics, thus are objective; in other words, one's personal credences about a certain outcome or a system are simply untreated in the Boltzmann viewpoint (Uffink, 2011 p. 41).

C.2.1 ***Frequentism***

This treatment of the frequentist interpretation is based on the studies conducted on ‘Interpretations of Probability’ by Hájek (2019), therefore, the notions considered in the next lines are grounded on that work. The frequentist account of probability deals with the frequency of the occurrence of a given event. The above mentioned frequency is linked to probability. Indeed, according to the frequency interpretation of probability, probabilities are identified with relative frequencies. (This locution stands for the frequency of a certain outcome divided by all the outcomes. For example, if a coin is tossed ten times and heads is landed five times, the relative frequency of heads is 5/10. In other words, it is 50%.) Basically, there is a relationship of identity between probability and relative frequency. Thus, considering again the example of the coin toss, the probability of landing heads is the relative frequency of heads observed in the long run (i.e. if one keeps tossing the coin for a significant number of times, or in other words, if one keeps tossing the coin in a very high number of trials). There are two different frequentist perspectives. The first one is the so-called finite frequentism and the second one is the hypothetical one. With regards to finite frequentism, this account has been developed by Venn and is widely applied in statistics. According to this type of frequentism, the reference class considered is finite and actual. This means that the probability of an outcome is related to a finite reference class considered. In other words, only actual trials are considered. On the contrary, hypothetical frequentism states that there is an identity between probability and hypothetical frequency. In this case, the actual trial is extended infinitely, so probabilities are the relative frequencies associated to such an infinite - and hypothetical - sequence.

A quick thought on Quine is needed in this phase of the work. Specifically, the hypothetical type of frequentism seems to be unavailable to Quine and probably Quine would have not adhered to this type of frequentism. Reasons in support of this thought are related to the modal aspect inherent to this type of frequency view. In fact, in this case a counterfactual element is involved since there is no set of trials that lasts indefinitely in the real world: hypothetical frequentist reasoning appears to be modal reasoning about what would happen were an infinite number of trials to occur.. Moreover, even if Quine were to use the mathematics of limits to get around the problem of infinite number of trials, considering the frequency as the limit as the number of trials get larger, this still seems to be problematic. This is because there is a small finite cap on the number of actual trials that have taken place, hence modality creeps in again as we are talking about the limit that would occur had larger and larger sized trials taken place.

It looks, then, as though if Quine were to adopt a frequentist perspective he would have to opt for finite frequentism. However, even though finite frequentism is more in line with the Quinean perspective (having various applications in science and being extensional), it runs into a number of problems as the other frequentist perspective. The major issue is the so-called single-case problem (Hájek, 2019). The single-case problem is particularly difficult to overcome for frequentists because a number of natural events cannot be repeated more than once (*Ibid.*). For example, the Big Bang is a physical event that cannot be reproduced exactly the same way twice. So, how could one calculate the probability of singular events? This issue is mentioned by Smokler, amongst others, in 'Three Grades of Probabilistic Involvement*'* (1977, p. 137) and it is the reason why Smokler (1977) takes into account the single-case propensity view. Another issue related to all the frequentist accounts is the reference class problem. In particular "The reference class problem arises when we want to assign a probability to a proposition (or sentence, or event) *X*, which may be classified in various ways, yet its probability can change depending on how it is classified". (Hájek, 2007 p. 563). Indeed, relative frequencies are linked to a reference class. Attempting to make an example inspired by the one reported by Hájek (2007 p. 564), we could say if one wants to calculate the probability of a middle-aged woman called Lucy of living more than seventy years one needs to consider a number of reference classes (i.e. the class of middle-aged humans, the class of women, the class of middle-aged women, the class of people who have two consonants in their name and so on...). It is quite clear that the relative frequency of people who live beyond seventy years is different in all the above mentioned reference classes. So, it is difficult to establish what is the reference class that should be considered to calculate the probability of the middle-aged woman Lucy of living more than seventy years. With regards to our discussion, probability intended as frequency is often employed by scientists, but the type of probability taken into account in QM seems to imply a different type of probability that diverges from simple frequencies. More on this, will be discussed in Chapter III with the example of radioactivity.

C.3 ***The propensity interpretation of probability***

A description of the propensity interpretation of probability in this work is motivated by the fact that Quine hints that an extensional propensity view could be adopted to account for probability in QM instead of a subjectivist account of probability (2008). Thus, exploring the “traditional” way of intending propensities clarifies this concept laying the foundation to a discussion on a potential use of extensional propensities to understand probabilities in QM. The propensity interpretation of probability was conceived for the first time by Popper, and it falls among the scope of physical or objectivist interpretation of probability together with frequentism as we mentioned above. This latter account, (Popper, 1959 p. 26) admits, was criticised even if he also advocates the idea that there is some possibility “to construct a frequency theory of probability that avoids all the objections which have been raised and discussed.” (*Ibid.*). Popper (1959, pp. 26-27) also says that he has has been able to develop a frequentist theory that overcomes the usual criticism but he also specifies that there are two reasons why he gave up with the frequentist account of probability:

> (1) The first was connected with the problem of the interpretation of quantum theory. (2) The second was that I found certain flaws in my own treatment of the probability of *single events* (in contrast to sequences of events), or 'singular events’, as I shall call them in analogy to 'singular statements’(Popper, 1959 p. 27)

Thus, Popper develops the idea that probability cannot always be identified with frequencies. To be more specific, in the case of coin tossing, frequentists consider the probability of landing heads as the long run relative frequency of landing heads. This means that, in the long run this frequency will converge on 0.5 for a fair coin (Popper, 1959 p. 26). Therefore, according to frequentism, probability is not a property of each coin toss. On the contrary, it is linked to a potentially infinite or finite sequence of coin tosses. Popper (1959 pp. 31-32), on the other hand, explains probability in terms of propensity and uses the example of two dice: a fair and a loaded one (which is heavier than the other on a side) to clarify his perspective. Both of the above mentioned dice are able to generate long run frequencies when one tosses them. But, according to Popper, it is the two dice's different physical characteristics that are causally responsible for their behaviour as they show different results, as we extrapolate from the article (1959). The physical properties of the dice are called propensities:

> For propensities may be explained as possibilities (or as measures or 'weights' of possibilities) which are endowed with tendencies or dispositions to realise themselves, and which are taken to be responsible for the statistical frequencies with which they will in fact realize themselves in long sequences of repetitions of an experiment. Propensities are thus introduced in order to help us to explain, and to predict, the statistical properties of certain sequences; and *this is their sole function."* (Popper, 1959 p. 30).

Moreover, Popper (1959 p. 31) explains that a major point in favour of the propensity interpretation regards the possibility to avoid unwanted aspects from QM; the unwanted aspects considered by Popper are elements of the subjective kind that he thinks have a more metaphysical character than propensities. Furthermore, an important feature of these propensities is that they belong to individual experimental arrangements making scientists able to talk about single-case probabilities (Popper, 1959). This is clearly an important theoretical advantage of the propensity view over frequentism and it explains the long-run frequency behaviour of chance setups (*Ibid.*). Also, we could think that the propensity interpretation could be a way to interpret the probabilities associated with QM properties like the decay rates of atoms. Popper interprets QM properties as measuring indeterminacies in the world, not just our ignorance of the physical events, e.g., at the moment of atoms' decays. Plus, Popper (*Ibid.*) thinks that the propensity interpretation is the most natural way to interpret the QM probabilities in physics.

C.3.1 ***Reasons behind the propensity view***

QM has a major role in the development of the propensity view, as considered by Popper himself in 'The Propensity Interpretation of Probability' (1959). Therefore, given the weight QM has in the elaboration of the propensity view, it may be said that the propensity perspective has been developed with QM in mind. Specifically, the Double Slit Experiment played a major role in Popper's brainstorming for the propensity viewpoint. To be more specific, Popper (1959, pp. 27-28) says that

> it was only after I had developed, and tried out, the idea that probabilities are *physical propensities,* comparable to Newtonian forces, that I discovered the flaw in my treatment of the probability of singular events. (…) I also produced an explanation of the interference experiments ('two-slit-experiments'), but I later gave this up as unsatisfactory. It was this last point, the interpretation of the two-slit-experiment, which ultimately led me to the propensity theory: it convinced me that probabilities must be 'physically real'—that they must be physical propensities, abstract relational properties of the physical situation, like Newtonian forces, and 'real', not only in the sense that they could influence the experimental results, but also in the sense that they could, under certain circumstances (coherence), interfere, i.e interact, with one another. Now these propensities turn out to be *propensities to realise singular events.* It is this fact which led me to reconsider the status of singular events within the frequency interpretation of probability. In the course of this reconsideration, I found what I thought to be independent arguments in favour of the propensity interpretation.

Therefore, Popper develops the propensity perspective of probability motivated by the Double Slit Experiment and to make sense of probability in QM; not only to solve the issue of single-case probability. Indeed, it appears clear from Popper's words that the issue of single-case probabilities just self-corrected with the introduction of propensities.

C.3.2 ***Issues with the propensity view***

The major drawback that the propensity perspective faces is the metaphysical *status* of propensities. Indeed, since propensities are not metaphysically clear it is not evident what propensities are exactly. This is shown by Lacey (2014):

> The propensity theory, substituted by Popper for the frequency theory, defines probability as a propensity of objects themselves, e.g. of a die to show a six. Popper claims propensities are no more 'mysterious' than gravitational fields,

> but one can still ask just what propensities are and how wide an area the theory covers. The word ‘chance’ can also be used for ‘propensity’, and for objective probability when this is distinguished from subjective degrees of belief. (Lacey, 2014 p. 272)

Indeed, while relative frequencies or subjective degrees of belief are not metaphysically mysterious, propensities seem to be unclear and the majority of us would find difficulties in defining them. Propensities are, from a metaphysical point of view, physical tendencies or dispositions. Indeed, they can be read in terms of probabilistic dispositions. But clarifying this idea is challenging. That is why the term propensity is seen as a vague concept that does not add to our understanding of what generates those frequencies. Surely, from a Quinean perspective, propensities as Popper intends them, could be metaphysically problematic as they are considered as physically real entities or forces (Popper 1959, p. 27 and p.37), In this case, *de dicto* modality does not enter the discussion. Indeed, in the case of propensities as they are treated by Popper (*Ibid.*) modality is *de re*. The idea that propensities deal with *de re* modality seems to be supported (see Smokler, 1979) and this seems to be true both for long-run interpretation of propensities and the single-case one. Indeed, first of all, Smokler (1979 p. 498) defines the propensity interpretation of probability as an “explicitly intensional” perspective. Secondly, Smokler (1979) regarding the two types of propensity theory, i.e., the long-run and single-case one says:

> Some authors claim that these kinds of dispositional properties are predicable of a set of objects of a certain kind and this view can be identified with the long-run propensity interpretation, while others claim that these dispositional properties are predicable of singular individuals or events. The latter view has come to be called the single-case propensity interpretation. Both of these interpretations, as I have said, treat propensities as dispositional properties; the logical form of statements ascribing these dispositional properties to individuals or to collections of individuals involves a subjunctive conditional of one form or another. In other words, if physical probability statements are statements of propensities being attributed to individuals, then these statements are modal for there is no doubt that the replacement of at least

> some entities by their extensional equivalents results in the extension of the statement being different. (In this case the subjunctive conditional is the modal operator; it is dyadic and has the complete proposition as its scope.) (1979 p.498)

Here, Smokler (*Ibid.*) recalls the subjunctive conditionals, i.e. term used interchangeably in the philosophy community with counterfactual conditionals that indicate both conditionals with false antecedent and conditional with true antecedent (Starr, 2021). Plus, Smokler (1979) states that "It is to be remembered that there are two types of propensity statements: universally generalized propensity statements, and singular propensity statements. In both cases I claim that they are *de re* statements" (1979 p. 501). Again Smokler (*Ibid.*) recalls the long-run and single case propensities mentioned above. Smokler (*Ibid.*) wants to demonstrate that statements about propensites involve *de re* modality and in order to do this, he proposes an argument already considered in 'Three Grades of Probabilistic Involvement' (1977). The argument relies on four probability statements taken into account by Smokler (1979 pp. 501-503) that are subsequently transformed into their logical forms following Fetzer's reading of them. At that point Smokler (*Ibid.*) notices that the above mentioned statements are *de re* statements and that if they were transformed into statements of the *de dicto* type their meaning would have not been preserved, as already noted in Chapter I. Also, after having performed the discussion mentioned above Smokler (1979 pp. 503-504) underlines:

> The acceptance of *de re* modalities signifies that one accepts the existence of possible worlds and possible individuals (some of which are actual) which possess necessary properties. This is the ontology which it seems to me the acceptance of single-case probabilities forces upon us. From another angle, Fetzer and Nute come to the same conclusion. They consider the semantics proposed by Henry E. Kyburg, Jr. in his article, 'Probabilities and Propensities,' BJPS, and show that Kyburg is unable to distinguish between the two kind of propensities discussed in the scholarly literature, the one 'long run' propensities and the other the 'single case' propensities, whereas they are able in their own semantics to account for it. For that reason the Fetzer-Nute approach is relevant. Although they do not formally develop a quantified nomological logic it is clear that they are concerned with one.

Therefore, while Smokler's article (1979) is focused specifically on the single-case propensity view, we notice that the same discussion performed on the single-case propensity perspective can be done for the long-run one, with *de re* modality involved in both cases.

C.3.3 ***Comparison between Popper's propensities and Aristotle's potentialities***

Given that a discussion on the metaphysical status of propensity has been performed in the previous lines, this paragraph is dedicated to further trying to understand what propensities are while linking this chapter of the thesis with the next one, which will treat Aristotle's *potentiae*. Popper in his article 'The Propensity Interpretation of Probability' (1959 p. 37) cites Aristotle's' tendencies (see Chapter III for a complete discussion on the theme) and he says that:

> propensities exhibit a certain similarity to Aristotelian potentialities. But there is an important difference: they cannot, as Aristotle thought, be inherent in the individual *things.* They are not properties inherent in the die, or in the penny, but in something a little more abstract, even though physically real: they are relational properties of the experimental arrangement—of the conditions we intend to keep constant during repetition. Here again they resemble forces, or fields of forces: a Newtonian force is not a property of a thing but a relational property of at least two things; and the actual resulting forces in a physical system are always a property of the whole physical system. Force, like propensity, is a relational concept. (Popper, 1959, p. 37)

The difference between propensities and potentialities is clearly explained by Popper, with propensities that are not inherent to objects resembling forces, but both propensities and potentialities are physically real. Despite the differences between *potentiae* and propensities, we notice one main resemblance. Indeed, both *potentiae* and propensities seem to share an ambiguous metaphysical aspect. This would be unwanted for Quine to say the least. Indeed, as will be considered in the next chapter, Aristotle's perspective is strongly rejected by Quine. Similarly, Quine in *Confessions of a Confirmed Extensionalist and Other Essays* (2008) prefers to specify that he would have adopted an extensional type of propensity; thus, it is questionable that Quine would have adopted entities with such a mysterious metaphysical status as the one exhibited by propensities.

Conclusion

To conclude, this chapter has been dedicated to the various interpretations of probability and their drawbacks in comparison with Quine's perspective. I suggested that, on the face of it, it appears that none of subjective probability, frequentism, or the propensity viewpoint cannot be implemented in Quine's philosophy as they stand to deal with the probabilities in quantum mechanics. I specifically evaluated how interpretations of probability could be classified either in the epistemic scope or in the physical one. After that, I investigated the subjectivist account of probability, the frequentist one and the propensity viewpoint. I have devoted the majority of this chapter to these three philosophical lines of thought because they are either explicitly cited by Quine or hinted in his works. Indeed, as I said before, Quine initially prefers the subjectivist account of probability over the others but at a later stage, given that QM is a very important theory of physics, he decides to consider probability as it occurs in QM in an objectivist way without sacrificing extensionalism. For this reason, I decided to consider both the propensity perspective (cited by Quine himself) and the frequentist view that is surely the most extensional one. I described all of these three perspectives and I briefly considered all their advantages and drawbacks in order to have a clear general picture of all of them. In the last part of the chapter, I examined how the propensity view compares with Aristotle's account of potentialities, highlighting the major difference between the two perspectives. In what follows I will build on the points suggested here to explore in more detail whether the probabilities in quantum mechanics can be accounted for from Quine’s extensionalist perspective.

Chapter III: QM and probability

In this chapter, I investigate the concept of probability in QM. In the first chapter of this work, I hinted that probability is considered differently in QM than in other branches of physics, noting that it seems to be a more substantial force that guides microscopic and, as a consequence, macroscopic phenomena. In this chapter, I delve into the various interpretations of QM and I look more closely at the role played by probability in this branch of physics. This reasoning has two purposes: to recall and support Quine's need to find a more suitable interpretation of probability in QM, and to emphasise that QM probabilities seem to express an inherent modal aspect of natural phenomena at the microscopic level. In section A, I take into account the major current interpretations of QM. Thus, in what follows I firstly consider the Copenhagen interpretation, which is widely regarded as the standard one. Secondly, I talk about the Many Worlds Interpretation and the Cosmological one that are strictly linked. Furthermore, I briefly consider the Hidden Variables Interpretation, Bohmian Mechanics and GRW perspective. Finally, I just mention QBism, a minor interpretation of QM which will be properly treated in Chapter V, where I will try to implement it in the Quinean philosophy. In section B, I consider how probability is interpreted in the Copenhagen interpretation of QM, taking into account Heisenberg's perspective on the theme and his viewpoint on tendencies. After that, a comparison of Heisenberg's viewpoint on probability in QM and Quine's one is carried out. Given that this work is naturalistic in spirit and embraces a kind of naturalism that is Quinean in its essence, Heisenberg's point of view as a scientist involved in the development of QM plays a crucial role. Indeed, it represents a way to look at physics to find philosophical truths. I also mention contemporary philosophical perspectives that share Heisenberg's viewpoint on tendencies or *potentiae* to fund my reasoning on a purely philosophical ground too. In section C, I finally examine *de re* modality and Aristotelian essentialism in Quine's philosophy, comparing it with the type of modality implied by Heisenberg. I conclude the chapter arguing that the type of modality involved in QM cannot be extensionalised, being *de re*.

Section A: ***Interpretations of QM***

Section A is dedicated to the various interpretations of QM. In A.1, the Copenhagen interpretation of QM is taken into account. While major aspects of this interpretation are considered, as occurs with the other interpretations in the next sections, the Copenhagen view on how probability is used in QM is closely examined. It will also pay attention to Bohr's presentation of the Copenhagen interpretation, outlining that he adopts a pragmatic perspective remaining silent about the ontology of QM, in contrast with Heisenberg. Moreover, a few issues with the Copenhagen interpretation of QM are described since due to these puzzling aspects of the Copenhagen theory, physicists and philosophers decided to develop other interpretations of QM. In section A.2, the Many Worlds interpretation and the Cosmological one are examined, highlighting their main characteristics. In section A.3, I look at the Hidden Variables interpretation of QM, Bohmian Mechanics (an alternative way to conceive QM), Collapse Theories and alternative but minor interpretations of QM, including QBism.

A.1 ***Copenhagen Interpretation: the standard one and how physicists use quantum theory***

An account of the Copenhagen interpretation of QM is offered by Stapp (1972), who clarifies in the first lines of the paper (p. 1098):

> The central point is that quantum theory is fundamentally pragmatic, but nonetheless complete. The principal difficulty in understanding quantum theory lies in the fact that its completeness is incompatible with external existence of the space-time continuum of classical physics.

This premise highlights that quantum theory is a complete theory and that despite its completeness it presents fundamental differences from classical physics in terms of the external existence of space-time. The Copenhagen interpretation of QM has been proposed by Bohr and Heisenberg in the late twenties and it presupposes that nature cannot be understood in terms of space-time realities.

> According to the new view, the complete description of nature at the atomic level was given by probability functions that referred not to underlying microscopic space-time realities but rather to the macroscopic objects of

> sense experience. The theoretical structure did not extend down and anchor itself on fundamental microscopic space-time realities (*Ibid*.)

As Stapp (*Ibid*.) notices, during the 30's the Copenhagen interpretation became the orthodox perspective on QM, and is accepted by the majority of physicists and books on the theme. Despite criticism mounted due to the fact that the Copenhagen interpretation has never been fully clarified neither by Bohr and Heisenberg nor by other scholars (Stapp, 1972 pp. 1098-1099), it still seems to be the favoured one. More on this will be said in Chapter V, where there will be shown the results of a poll conducted amongst a group of physicists and philosophers who sharply favour the Copenhagen interpretation over the other ones.

The Copenhagen interpretation of QM emphasises indeterminism. Indeed,

> Today the Copenhagen interpretation is mostly regarded as synonymous with indeterminism, Bohr’s correspondence principle, Born’s statistical interpretation of the wave function, and Bohr’s complementarity interpretation of certain atomic phenomena. (Faye, 2019 pp. 1-2)

Moreover, Rae (2012 p. 50) specifies that Bohr himself embraced indeterminism and considered it as a “fundamental fact of nature”. The reason why the Copenhagen interpretation of QM describes an indeterministic universe is due to the fact that the theory predicts the results of all the measurements only probabilistically. Specifically,

> Quantum physics is now generally admitted to be indeterministic in the sense that it implies the impossibility of predicting certain kinds of physical events, however complete our initial information may be concerning the physical system in question; given sufficiently precise initial information we may, however, predict the probability of these events, i.e. the frequency of their occurrence under sufficiently similar conditions. (Popper, 1950 p. 117).

And, the probabilistic aspect of quantum theory is highlighted by the fact that quantum theory is regarded as a procedure that physicists use to derive probabilities in the measurement process as Stapp (1972 p. 1099) specifies. An account of the wave function and the Born rule used to read off probabilistic predictions from the wave function has been given in Chapter I. To complete the discussion on the role of probability in standard QM, delving into the actual practice performed by physicists clarifies the role of probability on a pragmatic side. Indeed, Stapp (1972 pp. 1099-

1100) describes QM in the actual practice of physicists examining how physicists use quantum theory. Summarising the above mentioned passages that include several technicalities it could be said that a system is prepared in a specified way to be examined through the measurement process (Stapp, 1972 p. 1099). First of all, a wave function is produced taking into account the specifications A regarding the way the physical system is prepared and a set of variables (these latter ones represent the degrees of freedom of the system considered) (*Ibid*.). After that, a second wave function is produced by considering the specifications B on the measurement that is carried out after the preparation moment described above; also in the case of the second wave function, a set of variables that represent the degrees of freedom of the system are taken into account (*Ibid*.). After that, the transition amplitude, i.e., a transformation function dependent on the type of system that was prepared and on the type of measured systems, is calculated (*Ibid*.) Finally, it is derived the so-called predicted probability "that a measurement performed in the manner specified by *B* will yield a result specified by *B,* if the preparation is performed in the manner specified by *A"* (*Ibid*.)*.* All of the above describes how quantum theory is used in the physicists' everyday practice;

> The essential points are that attention is focused on some system that is first prepared in a specified manner and later examined in a specified manner. Quantum theory is a procedure for calculating the predicted probability that the specified type of examination will yield some specified result. This predicted probability is the predicted limit of the relative frequency of occurrence of the specified result, as the number of systems prepared and examined in accordance with the specifications goes to infinity. (Stapp, 1972 p. 1100)

Looking at the usage of quantum theory and the role of probability in scientific practice strengthens the idea that probability plays a pivotal role in QM. Also, this discussion completes the analysis of probability in QM carried out in Chapter I and highlights in a stronger way that probability is at the core of the phenomena described by quantum theory.

A.1.1 ***Copenhagen: Bohr and the pragmatic account of QM***

As previously considered, Bohr and Heisenberg developed the Copenhagen interpretation of QM. While this part of the chapter is focused on Bohr, section B will deal with Heisenberg's perspective and his philosophical considerations.

Prior to this discussion it should be underlined that the Copenhagen interpretation of QM is filled with ambiguity and what the Copenhagen interpretation means, entails and implies remains unclear, as noticed by Stapp (1972).

> Textbook accounts of the Copenhagen interpretation generally gloss over the subtle points. For clarification the readers are directed to the writings of Bohr and Heisenberg. Yet clarification is difficult to find there. The writings of Bohr are extraordinarily elusive. They rarely seem to say what you want to know. They weave a web of words around the Copenhagen interpretation but do not say exactly what it is. Heisenberg's writings are more direct. But his way of speaking suggests a subjective interpretation that appears quite contrary to the apparent intentions of Bohr. (…) The writings of Bohr and Heisenberg have, as a matter of historical fact, not produced a clear and unambiguous picture of the basic logical structure of their position. (Stapp, 1972 pp. 1098-1099)

Having made this initial comment, it should be noticed that more on Heisenberg's view on QM and the alleged subjective aspect injected into orthodox QM by Heisenberg is taken into account later in this chapter. Plus, the reasons why Bohr's perspective is being taken into account in this work are twofold: first, it is necessary to examine Bohr's observations to have a complete picture of standard QM and, secondly, the pragmatic approach adopted by Bohr with scarce hints on how to make sense of probability in QM is accepted by some physicists who are not concerned with philosophical implications of QM.

As a pragmatic interpretation of QM, Stapp argues that Bohr's Copenhagen perspective shows similarities with James' philosophical proposal according to which "an idea is true if it works" (Stapp, 1972 p. 1103). To sum up the Copenhagen interpretation of QM, Stapp (1972 p. 1105) considers:

> The logical essence of the Copenhagen interpretation is summed up in the following two assertions:
>
> (1) The quantum theoretical formalism is to be interpreted *pragmatically*.
>
> (2) Quantum theory provides for a *complete* scientific account of atomic

phenomena.

Point (1) asserts that quantum theory is fundamentally the procedure described in the practical account of quantum theory given in Sec. II[4].

The completeness of QM theory will be considered in more depth in the next lines, thus the discussion revolves here on the first point. Stapp (1972) explains the pragmatic aspect of the Copenhagen interpretation examining Bohr's words on the theme. Only two quotes amongst the several ones considered by Stapp will be reported here to clarify the argument:

> Bohr's commitment to a pragmatic interpretation of the quantum-mechanical formalism is unambiguous: " ... the appropriate physical interpretation of the symbolic quantum-mechanical formalism amounts only to predictions, of determinate or statistical character, pertaining to individual phenomena appearing under conditions defined by classical physical concepts" (11.64). " . . . the formalism does not allow pictorial representation on accustomed lines, but aims directly at establishing relations between observations obtained under well-defined conditions" (Stapp, 1972 p. 1106)

This clarifies the pragmatic standpoint adopted by Bohr, who is concerned with the workability of quantum theory only and how it is able to depict reality. What we need to consider in this part of the work is Bohr's ideas on a possible acceptance of fundamental randomness in nature. In the first place

> In regard to the irreducible statistical element in quantum theory, Bohr was at first ambivalent. An initial acceptance of the notion of a fundamental element of randomness or indeterminism on the part of nature is suggested by the statement: "...we have been forced...to reckon with a free choice on the part of nature between various possibilities to which only probability interpretations can be applied" (Stapp, 1972 p. 1106)

Later on it could be noticed a

> turning away by Bohr from picturesque notions of a inherent random element in nature itself, and the adoption of an essentially pragmatic attitude toward the statistical character of the quantum-mechanical predictions. (Stapp, 1972

4 The Section II of Stapp's article (1972) is about what I have summarized in the second part of paragraph A.1., i.e., how quantum theory is used by scientists.

p.1107)

From this it could be said that the way Bohr intends probability in QM implies the idea of adopting the so-called “shut up and calculate” attitude. This also seems to imply that there is no need to discuss issues about the ontology of QM or the potential implication of randomness in nature. This leads to a main observation: Bohr simply remains silent on ontology. In terms of reading Bohr's viewpoint in a Quinean light, it should be noticed that Quine's naturalism relies on the idea that scientific theories tell us what exists. Thus, in the Quinean speculation, ontology has an important place and is linked to science. Thus, in case QM tells us that there is no ontology, probably Quine would have accepted this. But, in the case of Bohr's Copenhagen interpretation of QM, it is not said that there is no ontology linked to QM. Instead, Bohr simply adopts his pragmatic attitude, which resembles the “shut up and calculate” one bypassing the ontological issues. The tight link between science and ontology in the Quinean picture puts Quine in the position of defining his ontological commitment and this seems to be demonstrated by his late attempt to make sense of probability in QM in terms of extensional propensities instead of remaining silent on it.

A.1.2 ***Issues with the Copenhagen Interpretation***

Indeterminism is undoubtedly the main problem for the Copenhagen interpretation according to some philosophers, but it is not the only one. Indeed, another crucial issue related to the Copenhagen interpretation regards the role played by the wave-function. In particular, the standard interpretation of Quantum physics illustrates that subatomic particles are described by a wave-function that obeys the Schrödinger equation. This equation represents how the state of a quantum system evolves over time. Problems arise when scientists perform measurements on quantum systems. To be more specific, one of the main issues is related to the collapse of the wave function when a quantum system interacts with a detector (as occurs in the Double Slit Experiment). To be clearer, when a measurement is taken on a quantum system, the wave function describing this system collapses, so that the wave function switches from ascribing a continuously changing probability to a feature of the system measured, to ascribing a precise value to the abovementioned feature. In the case of the Double Slit Experiment, for example, an electron’s position is described by its wave function as a continuously changing probability wave until the measurement is taken, and as a precise value once the measurement occurs. In other words, the wave is localised again. According to the Copenhagen Interpretation, an electron's wave function contains the whole truth about the electron's position, momentum, and so on, so that until a measurement of the electron's position is taken, it has no position, but only a continuously changing collection of probabilities of being detected at various positions.

To clarify, according to the Copenhagen interpretation, properties do not exist in physical systems until measured (so that it is not really the case that the electron has a particular position or spin value but we do not know it), but rather that it is only when measurements occur that properties become determinate. Hence the probabilities in QM are not just a result of our ignorance of what properties a quantum mechanical system really has. This feature of the Copenhagen interpretation means that one cannot view the probabilistic nature of the wave function as merely epistemic (i.e., relying on the idea that electrons could have a determinate position and it is only a matter of ourselves, who do not know what this position is, as considered by Einstein in the EPR argument). Therefore, this means that according to the Copenhagen interpretation, the wave function encompasses the whole truth about the electron.

However, at the point of measurement, the probabilities collapse to a certainty. This grounds the so-called measurement problem. Indeed, no physicist is able to say, how does a wave-function's collapse occur and we can only access the particles' realm but not the wave-functions' one because we cannot observe wave-functions. Due to this aspect of the Copenhagen interpretation other physicists developed new ways of interpreting the wave-function's collapse and tried in these ways to solve the measurement problem.

A.1.3 **Entanglement, non-locality and the EPR experiment**

Other major issues of the Copenhagen interpretation are entanglement and non-locality. These two concepts are strictly connected. Indeed, the phenomenon of entanglement occurs when subatomic particles that interact with each other, are perpetually mutually dependent. In other words, their states are dependent on each other. This leads us to the non-locality issue, according to which, particles seem to be able to know about each other’s state, even when they are far apart. The issues of entanglement and non-locality led Einstein, Podolsky and Rosen to formulate a thought experiment that generated the EPR paradox (Rae, 2012). To be more specific, since Einstein was not a supporter of QM’s unconventional results, he decided to show that QM is an incomplete theory; in other words, the EPR argument aims to demonstrate that the wave function does not represent the full story about the systems that it describes (Rae, 2012 p. 31). In addition, Einstein wanted to demonstrate that there are features of the system not included in QM theory that determine the results of measurement, so that quantum mechanical indeterminism is a feature of our ignorance and not of the world itself (*Ibid.*). The above mentioned features are called hidden variables and would determine the properties, i.e., position and momentum, of a system considered even though the hidden variables are unknown to us (*Ibid.*). Einstein, Podolsky and Rosen grounded their thought experiment on a proof by contradiction to highlight that non-locality and entanglement lead to untenable results; thus, assuming locality. Therefore, with locality in mind, the above-mentioned researchers assume that if there are two entangled particles P and Q, when P is measured, Q cannot be affected by the measurement. Thus, they conclude from what has been considered previously that the collapse state of Q must have been determined prior to the measurement process. This would mean that the Copenhagen interpretation of QM is wrong in thinking that the QM state contains all the facts about Q (Rae, 2012).

It is commonly known that non-locality and entanglement are considered by Einstein 'spooky action at a distance'. This entails that if a particle P is on the Earth and particle Q is on another planet (e.g. Mercury), once P is measured then Q is affected by this measurement and it collapses in one state (while previously it was in a superposition of states). In other words, this would mean that the information acquired when P is measured should reach Q instantaneously. Thus, this information should presumably travel faster than light. Importantly, this is still a vexed question whether the 'spooky action at a distance' is in accordance with Relativity, according to which no entity is able to travel faster than light; this theme has been considered by Rae (2012). Einstein, Podolsky and Rosen tried to demonstrate that concepts like entanglement and non-locality derive from a scarce knowledge of the quantum worlds. This led Einstein, Podolsky and Rosen to hypothesise the existence of some hidden variables capable of explaining entangled particles and non-local phenomena.

Unfortunately for Einstein and his collaborators, the reasoning put forward by the three scientists has since been disproven by Bell's theorem along with experimental observations, which demonstrate that a local theory of QM would contradict observed statistical correlations between entangled particles that are successfully used in QM. More precisely, Bell gave an empirical proof against local realism. Rae (2012 p. 47) highlights that

> it is impossible to avoid the revolutionary conceptual ideas of quantum physics by postulating a hidden-variable theory that preserves locality. Bell's theorem and experiment have shown that the observed properties of pairs of photons cannot be explained without postulating some correlations between the state of the measuring apparatus and that of a distant photon.

In particular, Bell's Theorem:

> is the collective name for a family of results, all of which involve the derivation, from a condition on probability distributions inspired by considerations of local causality, together with auxiliary assumptions usually thought of as mild side-assumptions, of probabilistic predictions about the results of spatially separated experiments that conflict, for appropriate choices of quantum states and experiments, with quantum mechanical predictions. These probabilistic predictions take the form of inequalities that must be satisfied by correlations derived from any theory satisfying the conditions of the proof, but which are violated, under certain circumstances, by correlations calculated from quantum mechanics. (…) Bell's theorem shows that no theory that satisfies the conditions imposed can reproduce the probabilistic predictions of quantum mechanics under all circumstances. (Myrvold *et al*. , 2021)

Experiments to validate the assumptions made by Bell were carried out by several research groups. And, scientists performed a number of experiments on photon's polarisation to prove Bell's Theorem and discovered that QM predictions were confirmed. Aspect (1999) has reviewed a number of experiments performed to test Bell inequalities. In the first line of an article published in *Nature*, Aspect (1999 p. 189) clarifies that it is impossible to pursue the idea that locality can be attributed to photons. Indeed, (*Ibid.*) thanks to experimental violations of Bell's inequalities it has been confirmed that two photons “must be considered a single non-separable object” when they are entangled but spatially separated by hundreds of metres. As highlighted by Aspect (*Ibid.*), Bell's Theorem arose as a response to the EPR argument, which is incompatible with the Copenhagen interpretation of QM. Moreover, it is worthy to underline that:

> Bell’s theorem changed the nature of the debate. (…) Bell proved that Einstein’s point of view (local realism) leads to algebraic predictions (the celebrated Bell’s inequality) that are contradicted by the quantum-mechanical predictions for an EPR *gedanken* experiment involving several polarizer orientations. The issue was no longer a matter of taste, or epistemological position: it was a quantitative question that could be answered experimentally, at least in principle.[5] (*Ibid*.)

Also, Aspect (*Ibid*.) clarifies that a series of experiments performed by several scientists put to test Bell's Theorem. Amongst the tests considered, Aspect (*Ibid*.) takes into account an experiment performed by himself and other collaborators in the '80's. Specifically, Aspect (*Ibid*.) recalls an experiment conducted relying on two-channel polarizers, as occurs in the EPR, which gave very clear results in support of Bell. Indeed, it has been seen that there was an unambiguous violation of Bell’s inequalities and an “impressive agreement with quantum mechanics” (*Ibid*.). Similarly, other experiments at Innsbruck show that

> The results, in excellent agreement with the quantum mechanical predictions, show an unquestionable violation of Bell’s inequalities. This experiment is remarkably close to the ideal *gedanken* experiment, used to discuss the implications of Bell’s theorem. (…) The violation of Bell’s inequality, with strict relativistic separation between the chosen measurements, means that it is impossible to maintain the image ‘*à la* Einstein’ where correlations are explained by common properties determined at the common source and subsequently carried along by each photon. We must conclude that an entangled EPR photon pair is a non-separable object; that is, it is impossible to assign individual local properties (local physical reality) to each photon. In some sense, both photons keep in contact through space and time. (Aspect,

5 Here *gedanken* refers to the EPR thought experiment.

1999 p. 190)

See Chapter IV for further discussions on locality in light of Bell's Theorem.

A.2 ***The Many Worlds Interpretation that tries to solve the measurement problem***

The Many Worlds Interpretation is conceived as a reaction to the measurement problem that occurs in the standard interpretation of QM and solves the issue by assuming that “since the measurement problem [...] is a consequence of collapse, we can presumably resolve it if collapse can be shown to be unnecessary” (Rae, 2012 p. 75). To do that, the wave-function is considered at face value, and the Schrödinger equation is taken as nothing but a description of reality. Indeed, the main concept underlying this interpretation is the existence of a branching universe, i.e. a universe that is divided every time a measurement occurs. Indeed, according to the many worlds viewpoint, when physicists take a measurement on a given particle that is in a superposition of many different states at once, each state occurs in a different place that is a version of our real world. Moreover, according to Everett (the creator of the many worlds perspective) there are infinite universes (*Ibid.*). To be clearer, as we pull out from Rae (2012) exposition, if an electron is in a superposition of two states at once and hits a detector, the detector is put in a superposition of states too, since it has to measure the above-mentioned electron in one place or another. Moreover, if a scientist checks out the results from the abovementioned detector then she is also put in a superposition of states due to the fact that she sees the particle in one place or another. Obviously, the results obtained in one place or another are mutually exclusive. This means that the universe splits in two branches that in turn split again infinitely. This interpretation of QM has attracted a number of people but also in this case there are a few issues. The major one regards probability. Indeed, as Rae (2012 p. 80) explains “there is the problem of defining probabilities in a context where, instead of alternative occurrences, everything possible happens.” In the case of the Many Worlds interpretation, it is not just a case of taking proportions of worlds (Rae, 2012). Indeed it is worthy to underline that, e.g., if we measure an electron, saying that there is a ½ probability of measuring the electron spin up does not mean that the electron is spin up in the 50% of worlds and spin down in the other 50% of worlds. This is due to the infinitude of branches which implies a major difficulty of taking proportions of infinities (Rae, 2012).

A.2.1 ***The Cosmological Interpretation that saves probability***

As I mentioned previously, the Many Worlds Interpretation is one of the most important perspectives on QM. In fact, in order to perfect it, the Cosmological viewpoint tries to make sense of the issue of probability that occurs in the Many Worlds interpretation. According to the Cosmological Interpretation, the ideas underlying the Many Worlds interpretation would be true if and only if the universe is infinitely big. Indeed, in this case scholars of the Cosmological Interpretation try to preserve probability with the idea that the infinite number of detectors and scientists who perform the experiment could be split in proportions and the probability of the occurrence of a result of an experiment would be linked to a specific portion of this infinitely big universe. Questions remain given that taking proportions of infinities is not a straightforward matter and we could notice that, e.g., if we consider half of a countably infinite set is still countably infinite or a third of a countably infinite set is still countably infinite. But, again delving in such a deep way in the Cosmological Interpretation is not a matter of this work.

Turning to the general issues with the Cosmological Interpretation, this viewpoint has a major drawback too: it is not testable; thus no one is able to say that it would be preferable to the Copenhagen one. This kind of drawback affects the majority of QM interpretations. In fact, a huge number of them cannot be verified through experiments that is why they encounter resistance among the scientific community. As previously considered it seems that the real turn with the Cosmological interpretation of QM regards the attempt of this interpretation of making sense of probability. Aguirre and Tegmark (2011) explain their Cosmological interpretation project saying that they study “the quantum measurement problem in the context of an infinite, statistically uniform space, as could be generated by eternal inflation.” Plus, the above mentioned scholars (2011) underline that probabilities in the Cosmological interpretation of QM are understood in terms of frequencies. Aguirre and Tegmark, after having considered that according to the Many Worlds interpretation, quantum probabilities can be interpreted in a frequentist way, say “We will show that in an infinite inflationary space, probabilities can be given a frequentist interpretation even in this case.” (2011). This suggests that they pursue the idea of interpreting probabilities in QM in terms of frequency with a new twist, i.e., arguing that in an infinite expanding space, probability in QM can be understood in terms of frequency. In the concluding remarks of the article they underline that in this way a number of QM issues are solved (such as the measurement problem and the collapse of the wave function) and they believe that reading QM problems in the cosmological light would help in making sense of them (2011). In particular Aguirre and Tegmark (*Ibid*.) underline:

> Modern inflationary cosmology suggests that we exist inside an infinite statistically uniform space. If so, then any given finite system is replicated an infinite number of times throughout this space. This raises serious conceptual issues for a prototypical measurement of a quantum system by an observer, because the measurer cannot know which of the identical copies she is, and must therefore ascribe a probability to each one. Moreover, as shown by Page, this cannot be seamlessly done using the standard projection operator and Born rule formalism of quantum mechanics; rather, it implies that quantum probabilities must be augmented by probabilities based on relative frequencies, arising from a measure placed on the set of observers. We have addressed this issue head-on by suggesting that perhaps it is not observer-counting that should be avoided, but quantum probabilities that should emerge from the relative frequencies across the infinite set of observers that exist in our three-dimensional space.
>
> To make this link between quantum measurement and cosmology, we have built on the classic work concerning frequencies of outcomes in repeated quantum measurements.

A few considerations should be discussed in terms of how probability is considered in the Cosmological interpretation picture. Aguirre and Tegmark (*Ibid*.) argue that “quantum probabilities must be augmented by probabilities based on relative frequencies, arising from a measure placed on the set of observers” and that “ quantum probabilities that should emerge from the relative frequencies across the infinite set of observers that exist in our three-dimensional space”. This means that probabilities are calculated by considering the frequency of the occurrence of a certain outcome that arises from experimental measurements made by an infinite set of observers. The main concept here is infinitude. This places a few issues in terms of defining infinite. From the point of view of logic, Keyser (1905) examines the concept of infinitude. While Keyser's (1905) article tries to make sense of infinite and infinitude taking into account its relationship with finite and relying on logic, the point to consider here regards how Keyser (*Ibid*.) explains the nature of infinitude. Indeed, it appears clear that there are difficulties in determining the very nature of infinitude:

> We agree with Professor Keyser when he expresses his conviction that the existence of the infinite cannot be proved, but we venture to supplement this brief statement of his views by the following suggestions: By infinite we understand a process which is to be carried on incessantly. If we think of a mathematical straight line as being produced without limits, we call it infinite. Should we ever try to draw on, even if it were done only in thought, we should soon find out that our line is always of a definite length and never truly infinite, for we would need an infinite time to complete the task. The rigor of logic forces us to admit that infinitude is a process in action, but not a concrete and ready thing. (…) for anything that is concrete must be definite and anything that is infinite can never be a concrete thing, but must be a process in progress. (...) Infinitude is an evanescent quality; it comes or goes according to the viewpoint we take, according to the task we set ourselves. (…) The infinite is the resource of all possible existence illimitable in its possibilities. (Keyser, 1905 pp. 127-129)

This difficulty in appraising the nature of infinite and the concept of infinitude has an impact on how to make sense of taking proportions of an infinite universe. It is unclear how to measure frequencies of an infinite set. Indeed, once there is an infinite set it is not at all straightforward to talk of proportions.

A.3 ***The QM interpretations that try to make sense of non-locality, entanglement and collapse***

Until now, I have taken into account just some interpretations of QM that try to solve the measurement problem, but as I said previously the measurement problem is not the only issue that affects the standard interpretation of QM. Indeed, non-locality and entanglement are puzzling issues too. In the next paragraphs, it will be talked about some interpretations of QM that make sense of the above mentioned issues.

A.3.1 ***The Hidden Variable Interpretation***

The idea underlying Hidden Variable theories is that when the entanglement between two electrons occurs (i.e. when two subatomic particles are mutually dependent), there is something underlying the actual state of the two particles that determines the values they take on measurement. In other words, according to this alternative way of interpreting Quantum physics, “quantum particles possess hidden properties in addition to those that can be and are observed” (Rae 2012, p. 28). This means that the particles are in a definite position that we just do not know until the measurement occurs. Unfortunately, Hidden Variable theories are considered outdated since Bell’s theorem and subsequent experiments proved that QM is incompatible with them, on the assumption of locality. Indeed, according to the abovementioned theorem “no hidden-variable theory that preserves locality and determinism is capable of reproducing the predictions of quantum physics” (Rae, 2012 p. 36). But, Hidden Variable theories can still be considered a valid interpretation of QM if the principle of locality is removed. That is why Non-Local Hidden Variable theories spread.

A.3.2 ***Non-local Hidden Variable theory par excellence: Bohmian Mechanics***

Bohmian Mechanics, also known as a non-local hidden variable theory or as pilot wave theory, was developed by Bohm and De Broglie. It is a

> slightly different form of hidden-variable theory [...] based on another interpretation of the wave-particle duality. Instead of treating the wave and the particle models as alternatives, this theory proposes that both are present simultaneously in a quantum situation. The wave is no longer directly detectable, as the electromagnetic wave was thought to be, but has the function of guiding the photon along and adjusting its polarisation. For this reason, it is often described as a ‘pilot’ wave (Rae 2012 p. 29).

The main idea of this theory is that particles move on underlying waves. So, the probability of a particle to appear in different places is explained in terms of an underlying wave that cannot be observed. The advantage of this interpretation is that determinism is preserved (as mentioned above, indeterminism is one of the main issues related to the standard interpretation of QM). But, again a number of issues appear also in the case of Bohmian Mechanics. Firstly, Non-local Hidden Variable theory's hypotheses are not testable. Secondly, as Rae (2012) explains, the mathematics used in Bohmian Mechanics is much more complex than the standard QM mathematics. Third, the pilot wave is an unusual kind of wave, being so different from the waves studied in classical physics that they have no energy and are not able to have effects on the associated particles; in turn, these latter ones have no effect on the wave behaviour. Finally, this type of theory does not preserve locality.

A.3.2.1 ***Quine, Bohmian Mechanics and a failure of simplicity***

Bohmian Mechanics could look like a promising solution for Quine, given that Bohmian Mechanics gets rid of indeterminism and would allow for the removal of objective propensities. Despite this, the argument pursued here is against the adoption of Bohmian Mechanics from a Quinean viewpoint. To support this claim, it is vital to look at Quine's principles of theory choice, which would prevent him to adopt Bohmian Mechanics over the standard one. As mentioned previously, Bohmian Mechanics uses a very complex kind of mathematics. The issue considered here deals with Quine's treatment of underdetermination. Hylton (2007 pp. 320-323) talks about this theme saying that:

> Of course we might find an empirically equivalent rival to our theory which was clearly superior in its simplicity and clarity. In that case we would simply adopt the new theory. Our theory is not an object which is fixed over time; at any given time, "our theory" is simply the best that we have at that time, but it will evolve as times change. If we find a superior one, we adopt it. This is scientific progress, whether the superiority of the new theory is a matter of better predictions or of other virtues. At any time we accept the best theory that we have as true, and we are realists about the entities posited by that theory. (Hylton, 2007 p. 322)

Furthermore, Colyvan (2019) in an article on the Indispensability arguments, which takes into account Quine-Putnam Indispensability argument, clarifies that:

> We will need to spell out what counts as an attractive theory but for this we can appeal to the standard desiderata for good scientific theories: empirical success; unificatory power; simplicity; explanatory power; fertility and so on. (Colyvan, 2019)

Both the quotes considered present the term “simplicity”. Therefore, it can be deduced that simplicity is a theoretical virtue for Quine and it should be taken into account when we chose a theory amongst other rival theories. We could say that it is the case that all things being equal, the simpler theory should be preferred. In terms of simplicity, Bohmian Mechanics appears to be more complex than standard QM. Moreover, Bohmian Mechanics makes the same predictions as QM, as shown by Tumulka (2021 p. 4):

> An analysis of Bohmian mechanics shows that its empirically testable predictions agree exactly with those of standard quantum mechanics, whenever the latter are unambiguous. Thus, Bohmian mechanics is a counter-example to the claim put forward by Niels Bohr (and often repeated since) that in quantum mechanics a single coherent picture of reality be impossible. In particular, it turns out that the statistics of outcomes of experiments are related to the operators known as “observables" in the same way as in standard quantum mechanics.

Therefore, combining the idea that mathematics is more complex in Bohmian Mechanics and the fact that the predictions made by Bohmian Mechanics and QM are the same, it should be concluded that Quine would have preferred QM due to its simplicity. In other words, we focus on the simplicity of the theory considered and its predictions. Arguably, given that standard QM and Bohmian mechanics make the same predictions, all things are (otherwise) equal, and so Bohmian mechanics should be dropped as more complex. Thus, Quinean principles of theory choice would speak against adopting Bohmian Mechanics over the simpler standard QM.

A.3.3 ***Collapse theories***

Another way of interpreting QM is focused on the collapse of the wave-function. For this reason, there are interpretations called alternative collapse theories. Among these, the Ghirardi-Rimini-Weber (GRW) theory, also known as spontaneous collapse theory, is the major one. This theory tries to explain the reasons underlying the collapse of the wave-function and to describe the dynamics of how the wave function localises. According to the GRW interpretation of QM, the wave function has an inherent probability (intended as chance) of collapsing spontaneously similarly to what happens to radioactive atoms when they decay. Moreover, while for a small particle, there is a very low probability that its wave-function collapses, for big groups of particles there would be an increase in the number of collapses due to the fact that if any of the abovementioned particles collapse, it influences the collapses of the wave-functions of all others. This is the reason why a neat separation between our deterministic world and the QM's indeterministic one can be appraised. In other words, it describes the boundary between these two realms. Furthermore, GRW has a main advantage: it makes testable predictions.

An important aspect to consider here is the ontology proposed by the GRW theory. While there are at least three different ontologies that can be derived from philosophical interpretations of GRW as examined by Peter Lewis (2006), here, the above mentioned interpretations will be set aside and the argument will focus on the ontology that can be drawn directly from GRW. Peter Lewis (2006 p. 228) specifies that GRW tells us that the nature of the world is ultimately made by waves. Indeed,

> The Schrödinger dynamics and the GRW collapse dynamics both describe the evolution of the wavefunction, and unlike Bohm's theory, no particles are postulated in addition to the wavefunction. In fact, if the GRW theory is true, it looks like what we have been calling "particles" are nothing but aspects of the behavior of the universal wavefunction; (Peter Lewis, *Ibid*.)

Since, for the purpose of the argument pursued here, more on the role of wave function in the ontology of GRW is needed, it will be considered Dorato and Esfeld's 'GRW as an ontology of dispositions' (2010) where dispositions are seen as fundamental in the GRW ontology. Setting aside this, Dorato and Esfeld (2010 p. 43) describe the ontology of GRW and say:

> In a nutshell, we think that GRW makes two fundamental ontological assumptions: (1) spatial superpositions of non-mass- less microsystems whose wave function has a spatial spread that is significantly greater than the new constant 10^{-7} m evolve into well-localized states in an observer-independent way, and independently of interactions with other physical entities, by means of processes of spontaneous localization. (2) Since these processes are irreducibly probabilistic, GRW is the only realistic interpretation of quantum theory that is indeterministic. What do these assumptions amount to? And how are we to understand these irreducible probabilities?

Answers to the final questions of the lines considered, are provided by Dorato and Esfeld (2010) in the subsequent pages of their article. But, focusing on the two passages cited above, i.e. the one by Peter Lewis (2006) and the other by Dorato and Esfeld (2010), we comment that a) the wave function plays a crucial role in the ontology of GRW and b) the role of probability is pivotal and this presupposes indeterminism in nature. Thus indeterminism and the probabilistic aspect of QM is left intact and nothing is said about how to interpret probability either extensionally or intentionally in “pure” GRW. Therefore, there is no substantial advantage for Quine to opt for GRW to make sense of his extensional propensities.

Additionally, GRW suffers from the so-called tails problem:

> The primary quantum mechanical equation of motion entails that measurements typically do not have determinate outcomes, but result in superpositions of all possible outcomes. Dynamical collapse theories (e.g. GRW) supplement this equation with a stochastic Gaussian collapse function, intended to collapse the superposition of outcomes into one outcome. But the Gaussian collapses are imperfect in a way that leaves the superpositions intact. This is the tails problem. (McQueen, 2015 p. 10)

This means that there is no advantage to adopting GRW instead of the standard QM in terms of solving the superposition of states problem. Thus, supplementing the QM equation of motion with the stochastic Gaussian collapse function represents an addition that has no clear advantages. Instead, in terms of simplicity GRW adds another element, i.e., the stochastic Gaussian collapse function; thus, appears to be less simple than standard QM and this would be unwanted by Quine who takes simplicity into great consideration as taken into account above talking of Bohmian Mechanics.

A.3.4 ***Quine, interpretations of QM and an introduction to Quantum Bayesianism***

According to what we have considered so far, we see that the Copenhagen interpretation and GRW retain objective propensities. This means that if either of those is correct the problem remains for Quine. On the other hand, the Many Worlds interpretation replaces propensities with frequencies, but with the difficulty of explaining how frequencies work in infinite branching worlds. Furthermore, Bohmian mechanics does suggest the possibility of avoiding propensities, but at a cost to simplicity, which is considered one of the main virtues to take into account in the process of theory choice for Quine. Other than these interpretations of QM, there are some minor ones. One of them is Quantum Bayesianism (QBism), according to which Bayesian probability is applied to quantum physics. QBism offers a subjective account of probability that might be an option for Quine but will be considered and rejected in a later chapter, i.e., Chapter V, where Quinean philosophy and QBism will be treated.

In the remainder of this chapter it will be considered what we ought to say about probability in QM if Copenhagen is right about QM indeterminism.

Section B: ***Heisenberg, Aristotle and Quine***

Section B, is dedicated to Heisenberg's perspective on probability in QM, how his thoughts relate to Quine's, and whether an inherent intensional character of nature seems to be presupposed in Heisenberg's speculations. This will highlight that the Copenhagen interpretation is sometimes linked with the idea that there are some tendencies that govern natural phenomena. Not all the Copenhageners agree with the idea that there are tendencies in nature, as highlighted by Mermin (1989), but given that the propensity view is somewhat accepted by Quine to explain probabilities in QM, I believe that an examination of what kind of tendencies are admitted by a Copenhagener such as Heisenberg could be valuable for this discussion. A comparison between Quine's viewpoint and Heisenberg's will be performed, making clear that Quine's perspective on propensities appears to diverge widely from Heisenberg's one, with Heisenberg not mentioning the necessity of rendering propensities extensionally and arguing that dispositional properties ground quantum measurements (Suárez, 2007 p. 423). In section B.1, I talk about Heisenberg's perspective on dispositions in QM. In particular, taking into account *Physics and Philosophy: The Revolution in Modern Science* (1958) I consider his thoughts about Aristotelian *potentia*. In section B.2, I examine the concept of potency or potentiality (i.e. *potentia*) in Aristotle's philosophy trying to understand if the abovementioned concept is interpreted in an extensional light in the Aristotelian philosophy. This investigation on Aristotle's viewpoint on *potentia* turns out to be useful to determine whether Quine’s project of extensionalizing propensities (i.e. dispositions) is in line with Heisenberg's perspective. In section B.3, I compare Aristotle’s *potentia* (which is read by Heisenberg in terms of tendency) with Quine’s account of dispositions, which are nothing but propensities or tendencies, to examine whether the two concepts are contrasting. In section B.4, I highlight how philosophers developed Heisenberg's perspective on tendencies and whether part of the philosophers' world backs the above mentioned viewpoint. After that, I turn my attention to Quine's view on *de re* modality, investigating the role of essential and accidental properties in the Copenhagen interpretation of QM and highlighting that extensionality cannot be applied to Heisenberg's potentialities. These latter issues are considered in section B.5. By contrast, in section B.6, I determine whether it is possible to interpret propensities in an extensional way in QM while adopting the standard interpretation of the above mentioned branch of physics. Finally, I conclude, arguing that the Copenhagen interpretation of QM is linked to an ontology made by probabilities that are not interpreted extensionally. Efforts of finding a way to interpret probabilities in QM extensionally, avoiding any modal element, will be made in the next chapters where I will propose alternative interpretations with Lewis' Best System account of laws of nature and QBism as potential ways out for Quine.

B.1. ***Physics says its word on probability in QM***

Physics and Philosophy: The Revolution in Modern Science (1958) by Heisenberg is a book rich in considerations on probability in QM. This book is crucial for several reasons. First of all, given that Heisenberg is one of the main contributors to the standard interpretation of QM, his idea on how to interpret probability in QM has a strong influence in this work. Secondly, citing Heisenberg's work is perfectly in line with the main aim of this thesis, i.e. preserve naturalism and consider physics the main *locus* where to find truths about probability, in accordance with the spirit of Quine’s naturalistic perspective. With regards to *Physics and Philosophy: The Revolution in Modern Science* (1958), Heisenberg talks about probability in QM in the third chapter. There Heisenberg specifies that the probability function “represents a tendency for events and our knowledge of events” (Heisenberg, 1958 p. 15). Moreover, “what one deduces from an observation is a probability function, a mathematical expression that combines statements about possibilities or tendencies with statements about our knowledge of facts” (1958 p. 19). Furthermore, at page 21 (1958) we find the complete description of the probability function.

> The probability function combines objective and subjective elements. It contains statements about possibilities or better tendencies (‘potentia’ in Aristotelian philosophy), and these statements are completely objective, they do not depend on any observer; and it contains statements about our knowledge of the system, which of course are subjective in so far as they may be different for different observers. In ideal cases the subjective element in the probability function may be practically negligible as compared with the objective one. The physicists then speak of a ‘pure case’”.

A close look at these passages highlight that there is a non-negligible subjective element injected in Heisenberg’s interpretation of probability which could lead us to think that Quine’s subjective probability is confirmed. On the contrary, it is worthy to specify that when Heisenberg talks about the subjective aspect related to the probability function he is not referring to subjective degrees of belief but just to the fact that another observer could be able to have more accurate information about the system one is measuring (1958 p. 15). Indeed, “Certainly, quantum theory does not contain genuine subjective features, it does not introduce the mind of the physicist as part of the atomic event” (1958 p. 23). This clarifies in a crystal-clear way that no Bayesian element is taken into account by Heisenberg.

B.1.2 ***More on potentia***

Apart from the subjective aspect accounted for in Heisenberg's treatment of probability in QM, I shall turn my attention to tendencies. Heisenberg’s concept of potentiality or tendency is closely linked to the Aristotelian one also because he talks about the passage from potency to the actual, thus he recalls the Aristotelian dualism of *potentia* and act and applies it to QM. In other words,

> the transition from the ‘possible’ to the ‘actual’ takes place during the act of observation. [...]we may say that the transition from the ‘possible’ to the ‘actual’ takes place as soon as the interaction of the object with the measuring device, and thereby with the rest of the world, has come into play; it is not

> connected with the act of registration of the result by the mind of the observer (Heisenberg, 1958 p. 22).

It is worthy to notice that Heisenberg underlines again that physicists' mental dimension is not a matter of interest when one tries to make sense of QM. Indeed, Heisenberg specifies that the transition from potential to actual has nothing to do with the act of measuring a result by an agent. Since Heisenberg relies on Aristotle's perspective on potency, turning attention to *potentia* is vital at this stage of the discussion.

B.2 ***What Aristotle said about potentia***

Cohen and Reeve (2021) explain clearly what is the potentiality/*potentia* for Aristotle (who expresses it in terms of *dunamis)* and they say that:

> Aristotle distinguishes between two different senses of the term *dunamis*. In the strictest sense, a *dunamis* is the *power* that a thing has to produce a change. (…) But there is a second sense of *dunamis*—and it is the one in which Aristotle is mainly interested—that might be better translated as 'potentiality'. For, as Aristotle tells us, in this sense *dunamis* is related not to movement (*kinêsis*) but to activity (*energeia*)(Θ.6, 1048a25). A *dunamis* in this sense is not a thing's power to produce a change but rather its capacity to be in a different and more completed state. Aristotle thinks that potentiality so understood is indefinable (1048a37), claiming that the general idea can be grasped from a consideration of cases. Activity is to potentiality, Aristotle tells us, as "what is awake is in relation to what is asleep, and what is seeing is in relation to what has its eyes closed but has sight, and what has been shaped out of the matter is in relation to the matter" (1048b1–3).

Moreover, according to Aristotle's words retrieved in the book V of Metaphysics:

> "potency" means the source in general of change or motion in another thing, or in the same thing qua other; [20] or the source of a thing's being moved or changed by another thing, or by itself qua other (for in virtue of that principle by which the passive thing is affected in any way we call it capable of being affected;(…)) (c) All states in virtue of which things are unaffected generally,

> or are unchangeable, or cannot readily deteriorate, are called "potencies." For things are broken and worn out and bent and in general destroyed not through potency but through impotence and deficiency of some sort; and things are unaffected by such processes which are scarcely or slightly affected because they have a potency and are potent and are in a definite state.
>
> Since "potency" has all these meanings (…) That which has the potency of changing things, either for the worse or for the better (for it seems that even that which perishes is "capable" of perishing; otherwise, if it had been incapable, it would not have perished. As it is, it has a kind of disposition or cause or principle which induces such an affection. (…) Even in inanimate things this kind of potency is found; e.g. in instruments; for they say that one lyre "can" be played, and another not at all, if it has not a good tone. (…) Thus the authoritative definition of "potency" in the primary sense will be "a principle producing change, which is in something other than that in which the change takes place, or in the same thing qua other." (Aristot. Met. 5.1019a - 1020a)

As I outlined previously, Heisenberg clearly refers to Aristotle's *potentia* when he talks about probability in QM. Moreover, potency is real according to Aristotle even if it is not actual. Indeed, Felt (1983), while examining philosophical discussions on possible worlds, underlines the fact that *potentia* is an inherent aspect of the actual by saying that in the current philosophical debate possibilities tend to displace "the Anti-Parmenidean (Aristotelian) notion of *potentiality*, as an intrinsic character of the actual".

B.3 ***Aristotle and Quine***

Before making a comparison between Aristotle and Heisenberg's viewpoint on *potentia* and Quine's account of dispositions, it is worthy to notice Quine's sudden change of heart regarding probability in physics. Indeed, the shift we appraise from subjective probability to propensities highlights that Quine would have seen subjective probabilities unsuitable to make sense of QM probabilities. As already seen previously in this work, Quine did not provide an updated account of dispositions in the light of QM. Therefore, in order to compare Aristotle/Heisenberg's potentialities with Quine's account of disposition to see whether there is accordance between the two perspectives, I will need to rely on what he said in *Word and Object* (1960) Quine says about objects that are able to dissolve in water that "What we have seen dissolve in water had, according to the theory, a structure suited to dissolving; [...] Dispositions [...] are conceived as built-in, enduring structural traits" (Quine, 1960 p. 223). This leads to the thought that both Aristotle and Quine agree on the idea that things have an underlying structure or principle that makes them capable to do a certain thing or to suffer a certain effect. To be more specific, when Quine says that a soluble object has "a structure suited to dissolving" (*Ibid.*) this recalls Aristotle's way of dealing with the concept of potentialities. Indeed, he links the concept of potentiality with capability, e.g. connecting the capability to perish with the idea that there is a disposition or potentiality for a given object to perish. Indeed, potency according to Aristotle represents the source of change. Similarly, for Quine dispositions are unmanifest traits of objects that induce a change in their structure or behaviour. Arguably, the main differences between the two perspectives lies in the rejection of disposition as they are in the Quinean case and his philosophical solution that yearns for extensionality.

B.3.1 ***Potentiae and extensionality***

A few points against an extensional treatment of Heisenberg/Aristotle's potentialities should be taken into account when considering a reading of QM probabilities in terms of extensional propensities. First of all, as explained in 'Three Grades of Modal Involvement' (1966) only *de dicto* modalities can be rendered in an extensional way, while Quine is persuaded that there is no way of extensionalizing *de re* modalities. These latter ones need to be rejected as they are without processing them further. Indeed, Matthews (1990 pp. 251-252) specifies that in the Quinean view an attribute is seen as an essential one when it is necessary and constitutes an object as it is. This means that Quine would define the case of Aristotelian *potentiae* as *de re* modalities. Specifically, the case of Aristotle's potency, constitutes a modality *de re* since it has to do with the intrinsic nature of a thing and not just to the way a thing is linguistically expressed, as occurs with *de dicto* modalities. Thus, the Aristotelian way of intending tendencies, which is also adopted by Heisenberg, seems to be rather different in spirit from Quine's one. In support of my thesis, Kastner, Kauffman and Epperson (2018 p. 2) clarify “For Heisenberg, potentiae are not merely epistemic, statistical approximation of an underlying veiled reality of predetermined facts; rather potentiae are ontologically fundamental constituents of nature”.

B.4 *Is Heisenberg’s viewpoint on potentia shared by philosophers?*

Heisenberg's perspective on potentialities in QM has been evaluated and to some degree accepted in the philosophical world, too. Indeed, a few philosophers have taken into account the question of whether Aristotelian *potentia* could be considered a valid way to contribute to the discussion around probability in QM. As I underlined previously, Heisenberg takes into account Aristotle’s concept of *potentia*, and this latter one is understood as an underlying substrate that grounds probability in QM. Aristotle’s potentialities are, I argued, very close in spirit to propensities or tendencies. Indeed, they endorse the same main feature of tendencies, i.e. the idea that they lead things to behave in a certain way, grounding frequencies. Moreover, philosophers who have adopted a standpoint on potentialities that is close in spirit to Heisenberg’s one albeit with differences, evaluate potentialities under the name of tendencies or propensities (like Popper). This means, that even though Heisenberg’s way of calling tendencies with the name of potentialities and invoking Aristotle regarding the issue of probability in QM is not shared by a huge number of philosophers, there is undoubtedly a group of scholars who think that tendencies/propensities are related to probability. Moreover, it is worthy of mention that there is at least a small group of philosophers who incorporate the concept of potentialities proposed by Heisenberg, in their philosophical solutions to the issue of probability. Defences of Heisenberg’s notion of potentiality are available in Suárez (2007) and Kastner, Kauffman, Epperson (2018).

B.4.1 *Kastner, Kauffman, and Epperson interpret potentiae*

Kastner, Kauffman and Epperson’s article (2018 p. 1) begins this way:

> It is argued that quantum theory is best understood as requiring an ontological dualism of res extensa and res potentia, where the latter is understood per Heisenberg’s original proposal, and the former is roughly equivalent to Descartes’ ‘extended substance.’ However, this is not a dualism of mutually

> exclusive substances in the classical Cartesian sense [...]. Rather, res potentia and res extensa are understood as mutually implicative ontological extants that serve to explain the key conceptual challenges of quantum theory.”

Clearly, in the case of Kastner, Kauffman and Epperson, Heisenberg’s perspective is accepted *in toto* without changing any of its features and encompassed in their philosophical system. In other words, they simply rely on Heisenberg's interpretation of probability in QM. Kastner, Kauffman and Epperson's paper (2018), shares one main aspect with this work, i.e. the idea of adopting a standpoint close to physics to solve the ontological issue of probability in QM in Quine's speculation. Moreover, Kastner, Kauffman and Epperson (2018 p. 4) suggest that they are “primarily concerned with proposing that quantum entities and processes are a particularly robust subset of [...] quantum potentiae (QP); and that “these are strong candidates for realism”. In other words, the abovementioned philosophers ultimately rely on Aristotelian ideas of potentiality to explain the quantum world.

B.4.2 ***How Kastner, Kauffman and Epperson encompass Heisenberg’s ideas in detail***

The main idea underlying the article ‘Taking Heisenberg’s Potentia Seriously’ (Kastner *et al.* 2018) is that widening our perception of what is real is the only way to solve the issues related to QM. In order to do that, Kastner, Kauffman and Epperson argue that it is crucial to take into account Aristotle’s philosophy. In particular, Kastner, Kauffman and Epperson (2018) embrace the idea that potentialities are real even though they are not actual. In fact, Kastner et al. (2018) believe that reality should not be restricted to actuality, i.e. to actual events or objects in space-time. And, we should accept the idea that “real” and “actual” are two different concepts and that *potentiae* belongs to reality too, regardless of their actuality. Furthermore, Kastner, Kauffman and Epperson (2018) underline that potentialities, being components of existence, complete the ontological framework.

As I already considered previously, Kastner, Kauffman and Epperson’s (2018) philosophical idea relies on Heisenberg’s viewpoint on potentialities, which in turn is grounded on Aristotle’s theory of *potentia.* Indeed, according to Heisenberg the wavefunction that expresses the probability of a particle to be found in a certain spot is just a quantitative description of Aristotle's potentiality. This latter concept, combined with *res extensa* provides Kastner, Kauffman and Epperson's philosophical framework. Indeed, they believe in a dualism of *res extensa* and *res potentia* that are not isolated, but connected. They are "*duality of mutually implicative concepts*" (Kastner, Kauffman, Epperson, 2018 p. 3). In other words, they propose

> a new kind of ontological duality as an alternative to the dualism of Descartes: in addition to res extensa, we suggest, with Heisenberg, what may be called res potentia. We will argue that admitting the concept of potentia into our ontology is fruitful, in that it can provide an account of the otherwise mysterious nonlocal phenomena of quantum physics and at least three other related mysteries ('wave function collapse'; loss of interference on which-way information; 'null measurement'), without requiring any change to the theory itself. (*Ibid.*)

To clarify, according to Kastner, Kauffman and Epperson (2018), under the name of *res potentia* fall quantum potentialities, which are a type of potentiality quantitatively defined, being strictly linked to quantum measurements. And, one of these potentialities will always become actual.

> In terms of our non-substance dualism, the de Broglie waves are the possibilities (res potentia), while the discrete localized phenomena are the actualities (res extensa). A possibility is, in principle, not a spacetime object; it is rather a *vehicle of enablement* (noncausal and inherently indeterministic) of spacetime actualities. Thus, a quantum entity, prior to actualization, is a nonlocal object (quantum potentia, QP). (Kastner *et al.*, 2018 p. 10)

The advantages of this viewpoint are clear since thanks to the introduction of quantum *potentiae* in our ontology, the quantum world's problems are instantaneously solved and e.g. a solution to quantum entanglement (according to which two separated particles are able to influence each other's state) is found (Kastner *et al.* 2018). Indeed, the article explains that in the case of quantum entanglement there is no secret signal that is sent from one particle to the other after the first particle being measured (*Ibid*.). Indeed, what happens is that being the state measured for the first particle is no longer available for the second particle (*Ibid*.). In other words, the abovementioned state has been cancelled from the list of potentialities for the second particle (*Ibid*.). Thus, an actual situation that is represented by the measurement performed on the first particle modifies the list of potentialities that exist in the universe due to the fact that one potentiality has become actual (*Ibid*.)..

In other words, they "simply allow that actual events can instantaneously and acausally affect *what is next possible* [...] which, in turn, influences what can next become actual, and so on." (2018 p. 5). This means that the measurement process is a real process that turns quantum *potentiae* into elements of *res extensa.* Strong doubts on a potential reading of QM probability in Quine's speculation in these terms arise since there is no aspiration to extensionality here and no effort is made to extensionalize the quantum *potentiae.*

B.4.3 ***Suárez and potentialities***

On the other hand, Suárez (2007) approaches the problem in a substantially different way. Indeed, Suárez' 'Quantum Propensities' (2007) is a paper in which four different ways of using dispositional notions to solve QM paradoxes are evaluated. The abovementioned ways are Heisenberg's potentialities, Margenau's latencies, Maxwell's propensitons and the selective propensity interpretation of QM, which is personally backed by Suárez. Suárez evaluates all the virtues and drawbacks of all the first three interpretations, concluding that the selective propensities account is able to encompass all the virtues that Heisenberg's potentialities, Maxwell's propensitons and Margenau's latencies have, avoiding the inherent drawbacks. Moreover, the other purpose of 'Quantum Propensities' (2007) is to use dispositional notions intended as selective propensities to explain two other interpretations of QM: the Ghirardi-Rimini-Weber (GRW) interpretation and Bohmian mechanics. Heisenberg's potentialities, according to Suárez, have a non-marginal role. Indeed, Suárez uses two main characteristics of Heisenberg's potentialities "The appeal to dispositional properties as grounding quantum measurements" (Suárez, 2007 p. 424), and the fact that Heisenberg draws

> a sharp distinction [...] between these dispositional properties and the quantum probabilities. For it is clear that for Heisenberg "potentia" are not merely an interpretation of quantum probabilities. On the contrary, it has been noted that the relationship between the quantum probabilities and these "potentia" is rather subtle on Heisenberg's view. The selective-propensity view

> that I will develop in Section 5 will also essentially distinguish quantum probabilities from their underlying dispositions (*Ibid.*).

In conclusion, also in this case Heisenberg's viewpoint on potentialities is considered as a vital alternative way of solving the quantum weirdness.

B.5 ***Quine, de re modality and demonstration that science and only science tells us what exist (included the existence of essential properties)***

In Chapter I, I delved into *de re* modality establishing how and why it represents a problematic degree of modality for Quine, in this part of the work I will answer to a number of questions about Quine's opposition towards *de re* modality, the idea that probability in QM is related to *de re* modality, and finally, how probability in QM exemplifies the third grade of modal involvement.

With regards to Quine's opposition towards modality, Tuboly (2015 p. 524) clarifies the issue by highlighting that

> one of the most important metaphilosophical commitments of Quine is that he reads the quantifiers objectually. The objectual interpretation of the quantifiers means that the admissible values of the variables bounded by the quantifiers are objects simpliciter.

Moreover, Tuboly (*Ibid.*) examining the third degree of modal involvement in the Quinean speculation clarifies that, with the third degree of modal involvement, modal operators attache to open sentences and "When we are concerned with open sentences the primary elements are just the *objects,* hence we attach the modal items [...] to the *objects."* (*Ibid.*). This leads to Aristotelian essentialism, which is undesirable for Quine because it implies that things possess essential attributes; and, in turn, these attributes are necessary to things. Thus, according to a Quinean perspective, when a modal operator is attached to an object (as occurs in the case of the third grade of modal involvement), modality is no more related to how the object is expressed, i.e. its linguistic form, but to something inherent to the object without which the object considered is other than itself. Tuboly reconstructs Quine's argument about the connection between *de re* modality and Aristotelian essentialism and its rejection in the following way:

“(P1) QML is committed to essentialism (P2) Essentialism is an untenable, incoherent view. (C) Therefore QML is untenable and incoherent.” (Tuboly, 2015 p. 527)[6]

For this reason, if one says that modality is *de re* (as occurs in quantified modal logic) she is straightforwardly committing to Aristotelian essentialism, in accordance with Quine’s viewpoint. Moreover,

> This kind of essentialism was incompatible with Quine’s (1953/1961, 156) scientific naturalism: ‘Such a philosophy is as unreasonable by my lights as it is by Carnap’s or [C. I.] Lewis’s.’ According to Quine the existential questions are to be dealt with by science and scientific inquiries: since philosophy is not in a position to answer these questions science has to inform us whether there are essential properties or not. Inasmuch the latter does not claim that there are such things, their conception is just plain metaphysics for Quine (1953/1966, 174): “[QML] leads us back into the metaphysical jungle of Aristotelian essentialism.” (Tuboly 2015 p. 526).

Therefore, according to the Quinean framework, Aristotelian essentialism is incompatible with his naturalism. Moreover, as Tuboly (2015 p. 526) notices, questions about what exists are delegated to science and, also in this case, science should tell us about the existence of essential properties. This aspect is crucial for the argument of this thesis. Indeed, having underlined once again that it is science that determines our ontological framework this will be of vital help when considering David Lewis' perspective in Chapter IV.

B.5.1 ***Essential and accidental properties and Copenhagen interpretation***

Essential and accidental properties are crucially involved in the discussion about Aristotelian essentialism. A standard definition of essential and accidental properties is:

> The distinction between *essential versus accidental properties* has been characterized in various ways, but it is often understood in modal terms: an *essential property of an object* is a property that it must have, while an *accidental property of an object* is one that it happens to have but that it could

6 Here, QML means quantified modal logic.

lack. (Robertson Ishii and Atkins, 2020)

As I mentioned previously, Quine believes that there is a link between *de re* modality and Aristotelian essentialism due to the fact that essential properties invoke the notion of necessity, and this latter one is a modal notion. Thus, the reasoning is consequential: Aristotelian essentialism is linked with *de re* modality and *de re* modality directly leads to Aristotelian essentialism, according to Quine. Both *de re* modality and Aristotelian essentialism are problematic for Quine due to the fact that Quine is not able to extensionalise *de re* modal contexts. For this reason, Quine simply rejects both modalities *de re* and Aristotelian essentialism. Due to the Copenhagen interpretation of QM, questions about the nature of probability in QM arise. Indeed, I clarified that Heisenberg's viewpoint on tendencies gives a nod to Aristotelian essentialism and Aristotle's perspective on essential properties. Nevertheless, there would seem to be a need for an explanation about the reason why a commitment to a fundamentally probabilistic nature leads to *de re* modality and Aristotelian essentialism. I will consider the above mentioned aspect using Heisenberg’s concept of tendencies.

As previously mentioned, Heisenberg adopts Aristotle’s concept of *potentia* to clarify the issue of probability in QM. In addition, according to Heisenberg potentialities ground probability in QM. In other words, electrons and other subatomic particles’ behaviour is governed by tendencies; thus, tendencies lead these particles to behave in a probabilistic way. This tendency of behaving probabilistically is inborn in the particles and has nothing to do with our ways of expressing linguistically particles’ behaviour. Therefore, given that the probabilistic behaviour is owed to tendencies, it seems to be essential to subatomic particles since it qualifies quantum particles as subatomic particles. Indeed, regardless of what Heisenberg and other philosophers think about tendencies, it appears to be central to standard accounts of QM that microscopic or subatomic particles distinguish themselves in comparison with other particles (i.e. the macroscopic ones) for their probabilistic behaviour. In other words, we cannot think about a microscopic particle prescinding from its probabilistic behaviour.

I am proposing a step by step demonstration of this in what follows. In the case of electrons, physicists have demonstrated that each electron has the propensity to be spin-up half of the time and spin-down the other half prior to the measurement. In other words, electrons have the tendency of being measured as spin-up 50% of the time and spin-down 50% of the time, as the wave-function (mathematically expressed in terms of a probability function) confirms. This means that electrons have the tendency of behaving probabilistically. Specifically,

> the probability function contains the objective element of tendency [...] It is for this reason that the result of the observation cannot generally be predicted with certainty; what can be predicted is the probability of a certain result of the observation [...] The probability function does – unlike the common procedure in Newtonian Mechanics – not describe a certain event but, at least during the process of observation, a whole ensemble of possible events (Heisenberg, 1958 pp. 21-22)

Moreover, in this case we clearly appraise that here modality is involved, since there is a tendency of the electron of behaving probabilistically; were it to be measured, in half of the worlds where it is measured it is measured as spin up, and in half of the worlds where it is measured, it is measured as spin down. The abovementioned tendency is inborn in the electron itself. In other words, the propensity of being spin-up half of the times and spin-down the other half is not accidental to the electron. Indeed, an electron cannot lack in the propensity of being half of the time spin-up and the other half spin-down.

Looking closely at the tendency of the electron to be half of the time spin-up and half of the time spin-down prior to measurement, reveals that no spin can be related to a given electron prior to the measurement. Therefore, before a measurement is performed electrons possess only a tendency of being measured 50% of the time spin-up and 50% of the time spin down. In the light of what has been said in the previous lines regarding the fact that being half of the time spin-up and half of the time spin-down is not accidental to the electron, it appears clearly that the type of modality involved here is *de re* and how the essence of electrons is constituted is taken into account. Therefore, also in this case *de re* modality and Aristotelian essentialism go together and, the tendency of behaving probabilistically is essential to the electron.

Indeed, an electron would not be as such anymore without its probabilistic behaviour. One last point needs to be considered here: whether it would be plausible to say that having the propensity/tendency/*potentia* of being 50% of the time spin-up and 50% of the time spin-down is independent from electrons' essences. To answer this question I rely on the Double Slit Experiment, where the wave nature of the electron shows only the probability of finding an electron in a certain spot of the screen. Of course, it would not be plausible to say that the tendency of being 50% of the time spin-up and 50% of the time spin-down is independent from electrons' essences since there is no electron in nature that behaves as a particle only; thus, as a localised entity that obeys to deterministic laws. As well as, there is no electron that lacks its natural feature of being half of the time spin-up and the other half spin-down. Indeed, having the tendency to behave probabilistically is one of the features that qualifies electrons as such. In other words, an electron necessarily tends to behave probabilistically in order to be as it is. Therefore, if one commits to a fundamentally probabilistic nature (i.e. ultimately made of microscopic particles that have the tendency to exhibit a probabilistic behaviour), this leads to a commitment to essential properties attributed to subatomic particles.

To conclude, as long as probability is intended as quantum mechanical probability, it exemplifies the third degree of modal involvement because when we "attach the modal items [...] to the *objects"* (Tuboly, 2015 p. 524) we are dealing with *de re* modality as Quine himself underlines and in Quine's eyes *de re* modality directly leads to Aristotelian essentialism.

B.5.2 ***Quine's propensities and Heisenberg potentialities***

We previously considered that potentialities and propensities could be used as synonyms that refer to the same concept. Thus, a question arises spontaneously: would Quine extensional propensities be compatible with Heisenberg's potentialities? I previously underlined that the regular propensity view is close in spirit to Heisenberg's viewpoint on potentialities. This means that, one could say that since Quine opts for propensities at the end of his philosophical career as is appraised in *Confessions of a Confirmed Extensionalist and Other Essays* (2008), Heisenberg's perspective and the Quinean one share similarities. On the contrary, this is not the case since Quine adheres to an extensional propensity perspective and not to the regular one, which involves intensionality as noticed above. Similarly, Heiseinberg's standpoint involves intensionality too. Therefore, since Quine would not be prone to interpret propensities intensionally, and vice versa Heisenberg is not prone to adopt an extensional interpretation of potentialities, the two viewpoints are not compatible.

B.6 ***Using old extensional accounts of dispositions to interpret QM probabilities extensionally?***

Quine believes that he could adopt an extensional propensity view in order to make sense of probability in QM, as he hints in *Confessions of a Confirmed Extensionalist and Other Essays* (2008). But the only extensional account of propensities or dispositions provided by Quine can be found in *Word and Object* (1960), where he explains how to get rid of the modal operator –ble at the end of dispositional terms. Anyway, even though we know that Quine develops an account of extensional dispositions, the above mentioned account does not satisfyingly account for propensities as intended in QM. Quine thinks that dispositional terms are not a problematic degree of modal involvement due to the fact that there is a subvisible structure that grounds them (Quine, 1960 p. 223). This subvisible structure is a structure that, even though it cannot be seen, is still physical. This is evident when we consider the relative term “M” introduced by Quine to extensionalize dispositional terms. “M” means “is similar in molecular structure to”. Thus, Quine simply renders extensional these group of modalities (i.e. dispositional terms), which are only *de dicto* modalities (due to the fact that intensionality lies just into the way of expressing them and is not related to what they are, according to Quine), by invoking a physical structure which guarantees extensionality. In this way, he extensionalizes these terms and also demonstrates that modality could be removed in this case. But, it should be remembered that interpreting something in an extensional way is just a logical device that helps to provide an extensional formalism. This is in contrast with the purpose of propensities, i.e. to provide a framework of what is behind the formalism as also highlighted by Suárez (2007) amongst the others. Doubts on attempting to use the same logical device previously used for the treatments of dispositions on quantum probabilities seem to be confirmed by Quine's latest approach in *Confessions of a Confirmed Extensionalist and Other Essays* (2008). Furthermore, in the case of QM we cannot evoke any physical subvisible structure free of modality since even at the most fundamental level, quantum particles (i.e.

microscopic particles) are well known for their probabilistic behaviour.

Perhaps Quine could argue that an object having a propensity of 0.5 of being measured spin up would mean that the above mentioned particle possesses a subvisible structure such that 50% of objects with the same underlying structure get measured spin up and 50% spin down, substituting modality appealing to frequencies; thus, evoking a relative frequency claim to replace modality. But, the above mentioned solution runs into problems with radioactive atoms as seen in the first chapter of this work, where it has been considered the decay of Carbon-14. Regarding radioactive decay, a review of Rutherford's discoveries on the theme is performed by Kragh (2012):

> As mentioned, in his study of 1900 of the properties of thorium emanation Rutherford had found that the activity of the substance decreased exponentially in time and thus could be ascribed a definite half-life. In his further investigation of the phenomena of decay and regeneration of radioactive intensity he joined forces with Soddy, which in 1902 resulted in the first version of the disintegration theory, to appear in a refined form the following year. According to Rutherford and Soddy, a radioactive substance transformed into another substance in the sense that the atoms changed from a "parent element" to another "daughter element" at a characteristic rate. *Not only do atoms change or transmute, they also do so randomly, such as expressed by a certain decay constant (λ) that depends only on the nature of the radioactive element.* (…) *As Rutherford was well aware, the decay law is of a statistical nature*, giving only the probability that an atom decays in some interval of time between t0 and t0 + Δt[7]. Some atoms will decay almost instantly, while others will survive for a much longer time. Another way of expressing this statistical nature is that a radioactive atom does not age: the probability of decay does not depend at all on the age of the atom, but only on its kind. Rutherford realized that the form of the decay law seemed to disagree with causal-dynamical models of radioactivity (*Ibid*. pp.7-9; my emphasis)

As mentioned above, the main aspect to consider is that radioactive atoms decay randomly and their decay depends only on the very nature of any given radioactive

7 Here t0 means at initial time and Δt means change in time.

element. This makes the decay a probabilistic phenomenon. It is not to say that considering a group of radioactive atoms, one establishes that 50% of them decay at a given time after having explored their behaviour. In the case of radioactive decay, any radioactive element possesses 50% the probability of decaying at a certain time. Again the fact that radioactive atoms decay randomly is linked to the nature of radioactive elements. Moreover, another part of the quote considered, i.e., the one related to the fact that radioactive atoms do not age (*Ibid.*) needs to be further considered. Indeed, given that radioactive atoms' nuclei do not age, we notice that the probability of seeing nuclear disintegration does not increase with time; instead, it remains constant over time. Thus, another crucial aspect of radioactivity is related to the fact that the age of radioactive atoms is irrelevant when it comes to predicting their decay. As already seen, this leads to establishing the half-life of radioactive atoms that indicates the overall decay rate for a significant number of atoms that exhibit the same feature. Therefore we notice that statistical sampling allows us to predict the half-life of radioactive atoms, playing a non-negligible role in the case of the radioactive atoms half-life definition. The idea that we could not make do with the statistical claim is clarified by the fact that the decay of radioactive atoms' nuclei is a random event at the level of each single atom, not depending on any other factor than probability. The above mentioned randomness has been taken into account in the quote above, but appears in an even clearer way in Chapter I [B.2.4], where we reported Salmon (2001) words that say that "*any* given Carbon-14" atom has the probability of decaying after a certain time. A major drawback against a simple statistical interpretation here is that statistics does not work for single atoms, while the probabilistic nature of radioactive atoms explains the statistics rather than the other way around. Indeed, in the case of radioactive atoms decay the statistics are explained by the probabilistic claims about radioactive atoms, rather than the probabilistic claims being derived directly from the statistics.

Another issue with the Quinean picture deals with the fact that subatomic particles are considered the foundation of our physical world. This means that, while Quine has the possibility of appealing to molecules to provide a physical and unproblematic ground to dispositional terms, nowadays molecules are no more the ultimate element in our physical world. Contrariwise, electrons, photons and other particles that express probabilistic behaviour represent the basic elements of our universe.

Moreover, and more importantly, it is vital to underline that using Quine's device to extensionalise quantum propensities is a dead end. More precisely, having the same basic structure does not guarantee that a given subatomic particle exhibits the same behaviour of another particle of the same type. Moreover, we cannot evoke a basic structure free of modality because quantum mechanical particles themselves exhibit probabilistic behaviour. This means that even the most primary structure cannot account for quantum particles' behaviour, as is seen with radioactive atoms that do not decay at the same time making decay a random process. Similarly, two quantum systems that have the exact basic structure can behave in different ways because one might collapse spin-down and one might collapse spin-up. So, when two given quantum systems are in exactly the same quantum state they can behave in two different ways because of the indeterministic collapse of the systems. This means that adopting Quine's account of dispositions is not sufficient to make sense of the probabilistic nature needed for the quantum systems. In conclusion, interpreting propensities in an extensional way is inappropriate for two reasons: the first one is related to the fact that the linguistic aspect is not even the main focus when taking into account QM probabilities and the second is that basic features of reality today depend on particles that exhibit a probabilistic behaviour.

Conclusion

In conclusion, in this chapter an argument against an extensional interpretation of probability in QM is presented. This chapter aims to demonstrate that Quine's old devices to extensionalise intensional contexts are unsuitable to render QM probability extensional. In other words, this chapter provides both an in-depth treatment of the problems that can be retrieved in Quine's philosophy and also the ground for further discussion and potential implementation of other philosophical perspectives in the Quinean one to save the latter from contradiction. In section A, I examined the main available interpretations of QM in order to have a clear perspective of current lines of thought in the physical debate on QM. After that, in section B, I considered Heisenberg's perspective on potentiality that seems to ground probability in QM. As I underlined, Heisenberg's viewpoint relies on Aristotle's concept of *potentia*. Moreover, I clarified that Heisenberg is one of the major contributors of the Copenhagen interpretation of QM, which is considered the standard one, so far. Finally, I also demonstrated that Heisenberg’s viewpoint, which seems to embrace *de re* modality, is shared by a number of philosophers like Kastner, Kauffman and Epperson and Suárez. All of them strongly believe that potentiality grounds probability in QM and in their viewpoints potentiality is not read in an extensional light. After that, I examined the reasons why probability in QM as grounded on potentialities cannot be interpreted extensionally also considering whether Quine's logical device to extensionalise dispositions could be functional in the case of quantum propensities.

Chapter IV: Does the Best System account offer a way out for Quine?

In this chapter, I explore the idea of including David Lewis' Best System account of laws of nature to address the issue of probability in Quine's system while preserving naturalism and extensionalism. In line with the spirit of Quine's philosophy and the aim of this thesis of maintaining Quine's perspective without distorting it, the argument concludes that David Lewis' viewpoint on laws of nature cannot be successfully implemented in Quine's system. Indeed, taking into account Lewis's perspective to overcome Quine's difficulties with probability in QM would mean discarding Quine's naturalism, which is something Quine would have not accepted. Along with the presuppositions of this thesis, this chapter is a building block of the reasoning pursued in the entire work, whose aim is to demonstrate that it is impossible to preserve all the aspects of Quine' philosophy in the light of the probabilistic nature of Quantum Mechanics without falling into inconsistency. The argument of the thesis represents a novel approach to Quine's philosophical perspective on probability in physics, paying attention to probability in QM. In section A, I present David Lewis' perspective. Therefore, I will examine all relevant aspects related to Lewis' account of laws of nature and his viewpoint on probability. In this section, attention is devoted to the development of a clear in-depth framework of laws of nature and how Lewis treats probability in QM. Also, I consider how the Humean base is constituted and Humean supervenience (HS) is taken into account. The lack of Lewis' intention of developing a framework coherent with quantum physics is also highlighted. This will be regarded as highly problematic for the potential implementation of Lewis' account in the Quinean philosophy. The main argument of the chapter highlights that attempts to merge Quine and Lewis' account of probability in QM are unsuccessful especially for the non-locality issue. Indeed, while aspects of divergence are highlighted by considering Lewis' treatment of dispositions, the difference between Quine and Lewis' naturalism and Lewis' way of dealing with extensionality, Lewis’ support of locality is deemed as an extremely problematic issue. I delve into all the aspects considered in the previous lines leading to the conclusion that Lewis' speculation is not decisive to solve the problematic aspects of Quine's philosophy when it comes to probability in QM.

Section A: ***Crucial aspects of Lewis' philosophy and how they relate to the Quinean outlook.***

In this section, I rely on a few important aspects of Lewis' philosophy to highlight the major points of divergence between Quine's perspective and Lewis' one. Specifically, Lewis' philosophical perspective is not considered in its entirety; rather, I pull out the few vital aspects that ground his account of probability in QM, shedding light on the major differences between Lewis' account and Quine's one. This part of the chapter represents the ground for the main argument of my reasoning being a point of departure for bringing out the idea that Lewis' system cannot be successfully implemented in Quine's one to account for probability in QM. In section A.1, I briefly recall Lewis' modal realism, one of the theses that pulls apart Lewis' speculation from Quine's. In A.2, I take into account Lewis's perspective on probability considering the infamous paper ‘A Subjectivist's Guide to Objective Chance’ (1980) and closely look at his account of laws of nature (and its drawbacks). Plus, I examine Lewis' HS thesis and the constituents of the Humean base. In A.3, I argue that there is a major point of divergence between HS and QM. This crucial divergence point emerges with the issue of un-localised entities. In A.4, I consider Lewis and Quine's treatment of dispositions making clear an additional divergence between the two philosophers. Finally, in A.5, I state that Lewis cannot be considered a Quinean naturalist.

A.1 ***The main aspects that pull Lewis's system apart from Quine's one***

Modal realism[8] represents one of the cornerstones of David Lewis' philosophical perspective and influences Lewis' entire philosophical system with its core thesis according to which our actual world is not the only one with several, infinite other existing worlds that differ from ours for little or substantial aspects or characteristics. Indeed in the Preface of *On the Plurality of Worlds* (1986a), Lewis spells out the

8 Lewis's modal realism is treated in *On The Plurality of Worlds* (1986a). Only general aspects are considered here. Specifically, I take into account a few aspects of modal realism to highlight the divergence with Quine's viewpoint on modality detaching the two perspectives and showing a basic disagreement between Quine and Lewis' philosophy.

main purpose of his book: "This book defends modal realism: the thesis that the world we are part of is but one of a plurality of worlds, and that we who inhabit this world are only a few out of all the inhabitants of all the worlds." (Lewis, 1986a p. vii). Moreover, inhabitants of other existing worlds are persuaded that their world is the actual one and each world is isolated since no one can inhabit more than one world. This means that no one can reach or visit the other worlds nor one is able to have direct proof of their existence. Precisely, Lewis (1986a p. 2) says:

> There are ever so many ways that a world might be; and one of these many ways is the way that this world is.
>
> Are there other worlds that are other ways? I say there are. I advocate a thesis of plurality of worlds, or *modal realism,* which holds that our world is but one world among many. There are countless other worlds (…) They are isolated: there are no spatiotemporal relations at all between things that belong to different worlds. Nor does anything that happens at one world cause anything to happen at another. Nor do they overlap; they have no parts in common (…) There are so many other worlds, in fact, that absolutely *every* way that a world could possibly be is a way that some world *is.* And as with worlds, so it is with parts of worlds. There are ever so many ways that a part of a world could be; and so many and so varied are the other worlds that absolutely every way that a part of a world could possibly be is a way that some part of some world is.

Lewis' ontology is a rich one including "countless other worlds" (*Ibid.*). Moreover, if we direct our attention for a moment from the ontological aspect of possible worlds to the issue of quantification that has been crucial in Quine's speculation, we find that Lewis believes that quantification over possibilities is required in several philosophical theories, especially in the best version of them. Lewis does not say that we cannot do without possibilities but admits that they render our philosophical theories better. Given this, Lewis extends the indispensability argument to possibilities that are not actualized as explained by Weatherson (2021 p. 49).

Furthermore, as Beebee and MacBride explain,

> In his "Counterpart Theory and Quantified Modal Logic" (1968), Lewis offers a radical alternative to QML. Whilst QML adds modal operators – the box

> (necessity) and diamond (possibility) – to our existing first-order logic, Lewis's "counterpart theory" simply extends the domain of quantification of first-order logic, so that it quantifies over not just the actual world and its inhabitants but all possible worlds and their inhabitants – related by the counterpart relation. The result is a logic into which the sentences of box-and-diamond modal logic can be translated, but which is stronger than QML (since there are sentences of counterpart theory that cannot be translated into QML) (Beebee and MacBride, 2015 p. 222)

Therefore, it seems that David Lewis' proposal falls in the debate about *de re* modality and offers a solution to the above-mentioned issue considering possible worlds. Lewis' solution is extensional since admitting the existence of other worlds, one is able to quantify over real but non-actual entities, which are present in the other worlds. The fact that the framework used is an extensional one is confirmed by the fact that Lewis uses first-order logic and simply extends its domain. Moreover, Lewis seems to be motivated by the same sceptical attitude exhibited by Quine towards *de re* modality as shown by Beebee and MacBride (2015). This leads him to conclude that essential properties are context-dependent. Relying on the example of a man called Jack who is necessarily human Beebee and MacBride (2015 p. 221) explain that according to a Lewisian perspective "whether or not Jack is essentially human depends upon the context within which we are asking the question: there is no absolute, context-independent fact of the matter."As previously said, Lewis relies on his Counterpart Theory to quantify over modal contexts. Indeed, the Counterpart Theory is proposed as an alternative to QML.

David Lewis' solution is expressed clearly in 'Counterpart Theory and Quantified Modal Logic' (1968):

> Instead of formalizing our modal discourse by means of modal operators, we could follow our usual practice. We could stick to our standard logic (quantification theory with identity and without ineliminable singular terms) and provide it with predicates and a domain of quantification suited to the topic of modality. That done, certain expressions are available which take the place of modal operators. The new predicates required, together with postulates on them, constitute the system I call *Counterpart Theory.* (…) The domain of quantification is to contain every possible world and everything in every world.

(Lewis, 1968 p. 113)

It is specified here that the domain of quantification contains every possible world and all the content of each possible world. Surely, this is a clear extensional framework. A framework able to solve the issue of *de re* modalities and QML. Whether Quine would be able adopt this framework to deal with the modal nature of quantum mechanical propensities is a matter for this chapter, but preliminary questions about how such a view could go hand in hand with a Quinean naturalist perspective arise. Indeed, even though Lewis' proposal is entirely extensional it is seen that even if the idea of enlarging the domain of quantification into possible worlds could remain unwanted for Quine but maybe the reliance on possible worlds would not be a major problem for naturalism that prescribes to found our ontology on our best scientific theories. Indeed, presumably Lewis would want to support the idea that the ontology of possible worlds is a part of our best scientific theories since it is part of the best explanation of how to understand their modal claims.

A.2 ***A few observations on probability in Lewis' speculation and first issues with the Principal Principle (PP)***

'A Subjectivist's Guide to Objective Chance' (1980) is Lewis' work where he sheds light on his perspective on probability. Lewis believes that there are two different kinds of probability (1980) opting for a twofold approach and interpreting probability both as subjective and objective. In a subjectivist way, probability is expressed in terms of credence and in an objectivist way, is seen as chance. With regards to this latter notion, Lewis defines objective probability as chance as appears clear from the first pages of the work (1980 p. 263). Chance is seen as the probability of the occurrence of a certain event in a world, considering the entire history of distribution of qualities in the abovementioned world. On the other hand, with regards to subjective probability, Lewis equals credence to the degrees of belief that an agent has in the occurrence of a certain outcome given a set of initial information. This latter definition recalls the traditional subjectivist interpretation of probability considered in Chapter II.

According to Loewer (2004 p. 1118)

> Lewis's account of chance is part of his more general Humean account of

> laws including laws of chance; the Best System Account (BSA). The account is "Humean" in that it characterizes laws as certain regularities and which regularities are laws is determined by the total pattern of instantiation of categorical properties.

Given that all aspects of David Lewis' philosophical perspective are interdependent, this passage leads to the treatment of laws of nature by Lewis. Thus, modal realism, the acceptance of counterfactuals and probability are closely linked with Lewis' view on laws of nature, which is linked with the theory of Humean Supervenience (HS), accordingly.

Before considering the above-mentioned aspects more deeply, I take into account another point that regards probability: the Principal Principle. More specifically, Lewis believes that the Best System Account of laws of nature should be chosen based on rational credences, which coincide with the chance, i.e. objective probability. In other words, when subjective probability coincides with the objective one, we can find the Best System account of laws of nature. In this framework, Lewis takes into account the so-called Principal Principle (PP). According to the PP, if a rational agent has all the information regarding a given event, his or her credence on the occurrence of the abovementioned event coincides with the objective probability of the occurrence of the event. Weatherson (2021 p.35) clarifies:

> The Principal Principle says that a rational agent conforms their credences to the chances. More precisely, it says the following is true. Assume we have a number *x*, proposition *A*, time *t*, rational agent whose evidence is entirely about times up to and including *t*, and a proposition *E* that (a) is about times up to and including *t* and (b) entails that the chance of *A* at *t* is *x*. In any such case, the agent's credence in *A* given *E* is *x*.

Therefore, the Best System account of laws of nature is based on subjective degrees of belief that correspond to objective chance.

The PP is deemed to be problematic given the fact that chance is grounded on the entire history of the distribution of qualities while credence depends on the available information at a given moment for an agent (Weatherson, 2021). Thus, chance and credence are destined to diverge (*Ibid.*) as I will consider again in the next paragraphs.

A.3 ***Laws of nature for David Lewis***

Lewis' probability is intertwined with his analysis of laws of nature, called the Best System Account of laws of nature, where credence and chance play a pivotal role. To determine which propositions express laws of nature and take part in the *corpus* of laws of nature, Lewis relies on two main principles: simplicity and strength (Weatherson, 2021). With regards to simplicity, this is not attributed to single events, but truths related to a collection of events; while, regarding strength, best systems should be based on strong and general truths, i.e. truths that are valid for the majority of the contexts and regard several events (*Ibid.*). In other words, only general truths in the best system could be considered laws (*Ibid.*).
Furthermore, in ‘Humean Supervenience Debugged’ (1994), Lewis adds a third cornerstone to simplicity and strength, i.e. fit; this third principle has been included by Lewis to make sense of chance, i.e. objective probability (*Ibid.*). Fit is about the fact that truths regarding phenomena that have a very high chance of happening are fitter than others (*Ibid.*).
Another characteristic of Lewis’ laws of nature is his picture of local facts. Indeed, according to Lewis the truth of a given law of nature depends on local facts. In this sense, laws of nature supervene on the Humean base (Loewer, 2004 p. 1118), which will be considered in the next paragraph.

A.3.1 ***A flaw in Lewis' viewpoint on subjective and objective probability, more on the issue of PP***

The relationship between subjective and objective probability, which are conjoined by the PP, raises some doubts that lead Lewis to write ‘Humean Supervenience Debugged’ (1994) to address the so-called bug in his theory. The above-mentioned problem is tied to the fact that subjective and objective probability can be merged with the PP with chance that constrains rational degrees of belief (Briggs, 2015 p.282).

In 'Humean Supervenience Debugged' (1994), Lewis acknowledges a flaw in his system. This flaw regards the combination of chance and credence stated by the PP. Indeed, while the chance is appraised considering the entire history of the distribution of qualities in a world, rational credence grounds on the information contextually available to each agent; thus, chance and credence end up diverging, and we have not even a sliver of hope of finding the best system of laws of nature. Lewis names this issue in his theory as the "big bad bug" (Lewis, 1994). Lewis never solved satisfyingly the "big bad bug" even though he tried to find a solution collaborating with Thau (*Ibid.*). Together they formulated the New Principle (NP) in place of the PP. According to the NP, there is a parallel between conditional credence and conditional chance. To be more specific, the conditional credence in a given statement *s*, given the chances of all statements, equals the conditional chance of *s*, considering the chances of all the statements (*Ibid.*). This solution, which seemed to be the only applicable one to Lewis, never satisfied him *in toto*. Indeed, he clarifies: "Our new version of the Principal Principle is better by Humean lights; but for myself, I still find the old one more intuitive." (Lewis, 1994 p. 489). Here, Lewis hints at the relationship between HS and PP with PP running into problems when read in the Humean light (Lewis, 1994). To clarify this, we may introduce the concept of HS.

A.4 ***HS: the basic aspects***

One of the main ideas that constitute Lewis' philosophical perspective is HS, according to which there is a supervenience base represented by a distribution of qualities. Also, there is a system of spatio-temporal relations. According to HS, the abovementioned properties and the system of spatio-temporal relations are all that exist at the fundamental level, with all facts supervening on these. Thus,

> The foundation of contemporary Humeanism is the conviction that there is some Humean base, often called the "Humean mosaic", of non-nomic, non-probabilistic fact, upon which all other facts supervene. There is a certain amount of haggling that can go on about the exact credentials needed to get into the Humean base. David Lewis thought that the basic Humean facts were also local facts—intrinsic features of pointlike or smallish regions or things—related only by Spatio-temporal relations (thus a "mosaic") (Maudlin, 2011 p.

300).

In other words, Lewis believes that there is a basic structure, i.e., the mosaic that is made of a series of properties that are intrinsic features of things, and the space-time reticule, as considered above. Thus, HS is a reductionist thesis, according to which different phenomena are interpreted in terms of other basic phenomena, also HS, with its arrangements of local facts, implies physicalism. There is no room in the supervenience base also for dispositions being analysed in terms of counterfactual conditionals (Lewis, 1997). With regards to dispositions or propensities, it should be stressed that, according to HS, dispositions must be rejected from the base since they cannot be reduced to the supervenience base, being fundamental irreducible features of reality. Indeed,

> for example, on Lewis's story the existence of fundamental dispositions is simply conceptually impossible, since what it *is* for something to have a dispositional property is for it to instantiate some categorical – and therefore non-modal – property such that its doing so, together with the laws, entails that it will behave in such-and-such a manner. (Beebee and MacBride, 2015 p. 234)

Further discussion on dispositions in comparison with Quine's account of dispositions is carried out in A.4.3, where major differences and discrepancies between Lewis' and Quine's views are taken into account.

A.4.1 ***What is the Humean Base?***

In the previous paragraph, I talked about the HS base, and I said that it is composed of a distribution of qualities. Now, I will clarify this and highlight its composition. According to David Lewis, the HS base is made of fundamental properties that are nothing but the above mentioned distribution of local qualities; these properties are natural intrinsic properties that are not affected by causality and thus, are categorical. Moreover, the above mentioned properties are not individuated by laws but induce laws of nature. For example, categorical properties could be shape and size. In other words, the Humean mosaic is composed of properties like geometrical structure; and, they are in line with our everyday intuition. Moreover, it should be stressed that a property is

> categorical just in case its involvement in laws is not essential to it. Lewis characterizes "Humean Supervenience" as the doctrine that (i) all the fundamental natural properties instantiated in the world are categorical and (ii) all truths supervene on the pattern of instantiation of fundamental properties. (Loewer, 2004 p. 1118)

Additionally, properties are merely contingently connected, not necessarily. So, according to David Lewis' viewpoint, properties represent what remains after having removed what is causal and modal. Indeed, categorical properties are non-causal and non-modal.

> Any modal truth whatsoever can be translated into a non-modal truth about similarity relations between possible worlds. In other words, necessary connections fall outside the scope of Lewis's explanation of the contingency of Humean supervenience: necessary connections between distinct existences *necessarily* supervene on non-modal features. So there are no irreducible necessary connections between distinct existences at this or any other possible world. (…) when it comes to *modal* features of the world, Lewis goes for full-blown reductionist conceptual analysis every time: necessary connections between distinct existences are to be "explained, or excused" (2001, 113). (Beebee and MacBride, 2015 p. 234)

Therefore, Lewis' treatment of modality has two main aspects: the first one is the introduction of alternative worlds and the other one is a clear extensional framework to rely on. This extensional framework is obtained by ruling out modality as the ultimate constituent of reality. This aspect sheds a Quinean light on the entire philosophical work of Lewis. But, even if extensionality would be preserved if we use Lewis' system in the Quinean one, it is unclear how to preserve Quine's naturalism.

A.4.2 ***Humean Supervenience, non-locality and Bell's inequality***

The analysis of HS compared with QM rules turns out to be important in light of Quine's naturalism. Indeed, looking at the possible accordance between HS and QM could constitute the starting point for potential implementation of Lewis' account into the Quinean one to clear out the contradiction occurring in this latter one.

According to HS, everything is localised, this means that there are no unlocalised entities. This represents a critical issue with QM. Indeed, one of the basic principles of QM is that particles are not always localised. In particular, there are fundamental physical entities (like electrons) that not only behave like localised points in space but also as waves, as the particle-wave duality principle tells us. Moreover, waves are not built out of point-like components. Being a wave or a particle is just a kind of way in which microscopic particles express themselves. Moreover, according to Bell's inequalities we need either get rid of the idea that there are localised entities or admit that there are other basic relations between entities than the spatio-temporal ones, contrary to what Lewis says (Weatherson, 2021 p. 43). Therefore, the HS base would need to include more than just the arrangement of point-like qualities and spatio-temporal relations to be in accordance with QM.

In support of the argument of non-locality in QM, Briggs (2009 p. 429) talking about Lewis' HS[9] underlines that LHS is untenable in the light of counterexamples both from classical mechanics and QM. The counterexamples Briggs refers to can be retrieved in Maudlin’s (2007) work where he examines one of the issues that affect Lewis' speculation in terms of Separability:

> (Separability): The complete physical state of the world is determined by (supervenes on) the intrinsic physical state of each spacetime point (or each pointlike object) and the spatio-temporal relations between those points. Separability posits, in essence, that we can chop up space-time into arbitrarily small bits, each of which has its own physical state, much as we can chop up a newspaper photograph into individual pixels, each of which has a particular hue and intensity. As the whole picture is determined by nothing more than the values of the individual pixels plus their spatial disposition relative to one another, so the world as a whole is supposed to be decomposable into small bits laid out in space and time. The doctrine of Separability concerns only how the total physical state of the universe depends on the physical state of localized bits of the universe. (…) If quantum theory is even remotely on the right track, then the best physical theories will continue, as they do now, to posit fundamental non-Separable physical states of affairs. (…) So before

9 Called by Briggs (2009) LHS.

> asking why one might want to be Humean, we shall review the evidence that the world is not Humean. (Maudlin, 2007 pp. 51-53)

Again the issue of localised entities represents a major threat to Lewis' perspective. Moreover, I argue that Lewis' position on HS becomes even less attractive for potential implementation in Quine's system due to its grounding reason. Indeed, Lewis admits to being concerned with finding a viable philosophical thesis than a thesis that would be in accordance with QM.

> Really, what I uphold is not so much the truth of Humean supervenience as the *tenability* of it. If physics itself were to teach me that it is false, I wouldn't grieve ... What I want to fight are *philosophical* arguments against Humean supervenience. When philosophers claim that one or another common-place feature of the world cannot supervene on the arrangement of qualities, I make it my business to resist. Being a commonsensical fellow (except where unactualized possible worlds are concerned) I will seldom deny that the features in question exist. I grant their existence, and do my best to show how they can, after all, supervene on the arrangement of qualities. (Lewis, 1986b p. xi)

But, this thesis is not looking for a well-crafted philosophical account unable to deal with the counterarguments posited by physics. Indeed, the purpose of this work is to maintain Quine's naturalism while examining naturalism and extensionality in Quine's speculation. Rejecting the idea of accordance between philosophy and science is not conceivable for Quine, who believes that there is no prior philosophy (Quine, 1981 p. 21). This means that a viable philosophical thesis, which tries to make sense of how nature is, should be in accordance with science. Thus, while Lewis could adopt a careless attitude about the tenability of his theory in physics, this thesis needs to care about this to maintain a Quinean naturalist viewpoint.

Turning the attention to physics, I stress that the rejection of non-locality leads also to the rejection of one of the major aspects of the standard interpretation of QM, i.e., entanglement. In particular, non-locality and entanglement are currently accepted by the scientific community and their place in the standard interpretation of QM highlight that they constitute one of our best scientific theories. Logically speaking, Quine would probably accept both non-locality and entanglement since they are described by our best scientific theories. HS is not in line with science therefore, it seems to be unable to make sense of the problematic aspects of Quine's philosophy.

A.4.3 ***Dispositions, the supervenience base and Quine's molecular structure***

In the previous paragraphs, I mentioned that in Lewis' picture, dispositions are not included in the supervenience base, with dispositions reduced to the Humean base. According to Beebee and MacBride (2015 p. 234), Lewis' accounts

> of laws (1973a, 72–7), causation (1973b), and dispositions (1997) in particular are all reductionist. (…) the instantiation of dispositional properties is analyzed in terms of the instantiation of categorical properties plus (again) facts about the laws.

I argue that Quine's appeal to the subvisible molecular structure in the treatment of dispositions present differences with HS.

Quine (1960) promotes a way to extensionalize dispositions using the relative term "M" which means "similar in molecular structure". In other words, Quine transforms dispositional terms into extensional ones evoking a basic kind of structure, i.e., the molecular one. To be more specific, a soluble object is no more "soluble" in the Quinean picture; instead, it has a molecular structure similar to another object that is suitable to dissolve in water. Quine's idea is just a logical device to extensionalize dispositional terms that are unwanted in the Quinean picture. Thus, Quine's idea is just a way to reject modality to opt for first-order logic, which is the only language that should be used to express our best scientific theories that tell us what exists, with our ontology being grounded on science as prescribed by Quine's naturalistic perspective.

A minor passage by Quine about dispositions clarifies how Quine's and Lewis' perspectives on dispositions presents differences (these differences do not lead to the idea that the two perspectives are irreconcilable straightaway, a major issues with the Humean base is treated in the next paragraph and that one could be considered highly problematic for HS):

> Each disposition, in my view, is a physical state or mechanism. A name for a specific disposition, e.g. solubility in water, deserves its place in the vocabulary of scientific theory as a name of a particular state or mechanism. In some cases, as in the case nowadays of solubility in water, we understand the physical details and can set them forth explicitly in terms of the arrangement and interaction of small bodies (1974, p.10)

Here, Quine underlines that there is a physical element under dispositional terms that is the "arrangement and interaction of small bodies" (*Ibid.*). Again, Quine recalls a subvisible structure that grounds the dispositional terms. And again, also in this case modality is *de dicto* and needs to be extensionalised. What pulls apart Quine's view of dispositions from Lewis one is related to Quine's attitude towards dispositions. Quine acknowledges that dispositions are "physical states or mechanisms" (Quine, 1974 p. 11) and can be described relying on the behaviour of small bodies. I believe that the small bodies Quine refers to are the molecules he talks about in 'Dispositions and Conditionals' (1960). It seems to be clear that these small bodies are basic. Moreover, there is no need to reduce them to something else (like the categorical properties of the Humean base). Quine refers to science that tells us what dispositions are, and he says "we understand the physical details and are able to set them forth explicitly in terms of the arrangement and interaction of small bodies" (Quine, 1974 p. 10). This underlines once again Quine's need to look at science to find his ontology. On the contrary, "For the physicalist and Humean could advert to the supervenience base for an ontological joint at which to divide the primary from the derivative (…) the properties and relations of the base would provide a well-defined (…) class of properties and relations to characterize reality completely and nonredundantly." (Shaffer, 2003 p. 511). As Shaffer (2003) underlines Lewis' main concern is to determine a supervenience base made of properties and relations that are basic for reality; probably more basic than molecules. And, the properties considered by Lewis ground reality and define all the entities in the reality.

A.4.4 ***David Lewis' basic structure and Quine's molecular structure. Is there a difference?***

In the previous paragraphs it has been highlighted that there is a difference between Quine and Lewis in the kind of basic structure that grounds reality. Indeed, while Lewis opts for a basic structure made of categorical properties, Quine gives a nod to the notion of molecules to explain the basic structure behind dispositional terms. Both the viewpoints deal with the idea that dispositions should be rejected as a basic constituent of reality. While it has been considered that a divergence between Lewis' proposal and Quine's one is just about the level at which the structure is described (molecular or more basic still), this does not appear to be a difference in spirit. Indeed, in this respect, Quine's viewpoint and Lewis' one on dispositions seems not to be irreconcilable. Both Quine and Lewis understand dispositions in terms of an underlying physical structure and how things with the same structure behave. Probably, Quine could drop his molecular structure in favour of the supervenience base; thus, Quine could quite easily agree that ultimately dispositions are grounded in more basic properties. Therefore, in this context an agreement between Quine and Lewis could be found. But, a major discrepancy appears once HS is compared with the truths proposed by science, which is, in turn, crucial for Quine. It has already been considered the issue of locality but it has not been evaluated the problem of dispositions with HS. Assuming that Quine accepts HS, dropping his molecular structure, and choosing a humean base, we could highlight that we face the same problems considered previously, i.e., when we have taken into account the issues of the probabilistic behaviour of certain atoms in relation with the subvisible molecular structure. The discussion that is going to be pursued in the next lines looks again at the issue of the decay of radioactive atoms, which has been treated elsewhere in this thesis. A fuller discussion on radioactive atoms and their behaviour has been performed in Chapter III; thus, just a quick recap of the above mentioned concept will be pursued here. Radioactive atoms’ behaviour has been considered fundamentally probabilistic when it comes to their decay. Indeed, the nuclear disintegration of radioactive atoms, i.e., their decay, occurs when unstable nuclei of atoms lose energy due to a phenomenon called radiation (i.e., the energy emission as either in the form of particles or waves through a material or simply space). All the radioactive atoms have an unstable nucleus. Alpha, beta and gamma decays are the main types of radioactive decay, where radioactive atoms emit one or several particles. In

'Introduction to Astronomy with Radioactivity', Diehl (2011) takes into account the various types of radioactive atoms decay and describes them:

> After Becquerel's discovery of radioactivity in 1896, Rutherford and others found out in the early 20th century that there were different types of radioactive decay (Rutherford, 1903). They called them α *decay,* β *decay* and γ *decay*, terms which are still used today. It was soon understood that they are different types of interactions, all causing the same, spontaneous, and time-independent decay of an unstable nucleus into another and more stable nucleus. *Alpha decay* : This describes the ejection of a 4He nucleus from the parent radioactive nucleus upon decay. 4He nuclei have since been known also as *alpha particles* for that reason. This decay is intrinsically fast, as it is caused by the *strong* nuclear interaction quickly clustering the nucleus into an alpha particle and the daughter nucleus. (...) *Beta decay:* This is the most-peculiar radioactive decay type, as it is caused by the nuclear *weak interaction* which converts neutrons into protons and vice versa. (...) *Gamma decay:* In γ decay the radioactive transition to a different and more sta- ble nucleus is mediated by the *electromagnetic interaction*. A nucleus relaxes from its excited configuration of the nucleons to a lower-lying state of the same nucleons. This is intrinsically a fast process; typical lifetimes for excited states of an atomic nucleus are 10−9seconds. We denote such electromagnetic transitions of an excited nucleus *radioactive* γ-*decay* when the decay time of the excited nucleus is considerably longer and that nucleus thus may be considered a temporarily-stable configuration of its own, a *metastable* nucleus. (Diehl, 2011 pp. 6-8)

Randomness grounds the process of radioactive atoms' decay. Indeed, the process of nuclear disintegration is regarded as a genuine stochastic phenomenon, and, in turn this randomness is basic, i.e., at the level of single atoms. Moreover, no matter how long the atom existed, there is no way of determining when a particular atom's nucleus will be disintegrated. The overall decay rate of some identical atoms is usually expressed in terms of the half-life of the atom, which comprehends a very large time span.

With regards to our reasoning, if we consider e.g., radiocarbon, each radiocarbon atom has 50% of probability of decaying after 5,730 years as considered in the previous Chapters of this work (i.e., especially Chapter III). A similar discussion could be pursued for things that dissolve when immersed in a liquid. Indeed, rather than saying that anything with the same base properties dissolves when put in water, we are saying that anything with the same base properties has a 50% chance of being measured spin up and 50% probability of being measured spin down. This would introduce probabilities into the supervenience base. An analogous reasoning could be pursued for the radiocarbon atom. Thus, also in the case of radioactive atoms probability is pushed into Lewis' Humean base. In the case mentioned above, the dispositional character is a fundamental constituent of the very nature of some atoms and cannot be reduced to something else. Plus, we have noticed that in the case of radioactive atoms, probability seems to be linked to a disposition each and every radioactive atom possesses, with probabilistic dispositions, i.e., propensities that involve properties that are fundamentally modal at base.

A.5 ***Is David Lewis a "Quinean" naturalist?***

I think that one of the main questions we should aim to answer is whether David Lewis is a naturalist. But, in this paragraph, I will not talk about naturalism in general. Instead, I will talk about a particular kind of naturalism, i.e., the Quinean one. In other words, I would like to determine whether Lewis embraces Quine's naturalism. According to Nolan (2005 p. 10) " Lewis's scientific realism seems to be grounded in his philosophical naturalism, which he shares with W. V. Quine, who was an important influence on Lewis". Whether Quine's naturalism and Lewis' one are the same is a matter for the next lines. First of all Nolan, (2005 p. 203) specifies that Lewis' philosophy has been influenced by Quine and considers Lewis a materialist. Plus,

> Unlike Quine, Lewis thinks that we need to distinguish some elite, objectively "natural" properties from the abundant sets. Lewis also thinks that we have to recognize many more concrete objects than Quine does; while Quine is prepared to recognize the existence of objects at other times than the present, he is not prepared to admit the existence of concrete worlds beside the actual.

(*Ibid*.)

One thing to notice is the fact that while Quine's naturalism implies a much more meagre ontology than Lewis'one, where only entities postulated by science exist; Lewis' ontology is very rich with a plurality of worlds with his very famous modal realism. Indeed, our actual world is just one amongst several ones. This could be considered just a disagreement between Quine and Lewis on the requirements of science, with Lewis thinking that the possible worlds theory is the best theory to make sense of the modalities required by science. Still, some common aspects between Quine and Lewis can be retrieved even when considering the plurality of worlds proposed by Lewis.

> Lewis explicitly compares his style of argument for possible worlds to an argument for accepting set theory (1986a: 3–5). Set theory is a "paradise for mathematicians", as the mathematician David Hilbert put it; it provides "great economy" in organizing and understanding mathematics. (...) As well as benefits in the simplicity of the basic postulates, and the fruitfulness of the unification of the basic concepts of mathematics that set theory can provide, set theory also has the advantage of explaining many different concepts in mathematics in terms of a handful of concepts. For example, we can explain all arithmetical operations, functions, and much else ultimately in terms of set-membership, and Lewis argues that we may be able to understand the set-membership relation itself in non-mathematical terms (see Lewis 1990, 1993c). Lewis outlines his strategy for arguing for the existence of possible worlds in a deliberate parallel. (Nolan, 2005 pp. 204-205)

In other words, in a pure Quinean spirit, Lewis explains his plurality of worlds; thus modal realism as something that has some benefits that outweigh the ontological costs and for this reason he believes that it is true, as specified by Nolan (*Ibid*.).

Moreover, it is considered that:

> When Lewis talks of reducing "the diversity of notions we must accept as primitive", he is talking about reducing the number of notions that we accept as basic and not further explained. The "unity and economy" of total theory is improved by taking a diverse class of phenomena, such as causation and

> belief and value and properties and others, and making sense of them in a unified framework. (…) Lewis has a commitment to a certain way of doing philosophy. It supposes that we have standards of economy and unity, and that we can somehow assess the theoretical benefits of a theory and set them against the costs. (*Ibid*.)

Furthermore, given the philosophical work natural properties do, the commitment to them is clarified and supported in the same way Lewis does with possible worlds (Nolan, 2005 p. 206). As I mentioned previously, Quine thinks that there is no prior philosophy and that philosophy is continuous with science. To date, science does not support the existence of a plurality of worlds that resemble Lewis' ones. And there is no demonstrated scientific theory according to which there are multiple worlds in the Lewis sense. This seems to suggest that Lewis could not be a Quinean naturalist. Thus, Lewis' attitude toward physics seems to underline that Lewis is not a naturalist in the Quinean sense. Indeed, in Quine's system, there is no space for alternative ontologies that do not rely on physics. Also in this sense, Lewis' speculation is again in contrast with Quine's one. What counts as another point of discussion on the theme is that probably Lewis does not invoke possible worlds as part of the best explanation of things that scientists do rely on, putting philosophy in continuous with science and claiming that there is a science-based motivation for adopting modal realism. Indeed, as considered in A.4.2, Lewis is very concerned with the philosophical aspect of his theory (Lewis, 1986b p. xi). In the above mentioned passage, Lewis (*Ibid*.), does not talks about modal realism, instead his words are dedicated to HS but as we underlined Lewis' philosophical theses are deeply intertwined and this sentence: “ If physics itself were to teach me that it is false[10], I wouldn't grieve” shows Lewis’ attitude and the fact that Lewis probably cannot claim that there is a science-based motivation for adopting modal realism.

Nolan (2005 p. 206) also specifies that:

> Lewis’s views about what the best trade-offs are no doubt differ from Quine’s, but his more general conception that this is an important part of philosophical theorizing has affinities with Quine’s methodological views. In some important respects, Lewis’s attitudes to the world differ from Quine’s. One example is

10 Here Lewis refers to HS.

> Lewis's approach to language, meaning and mental content. Quine tends to be suspicious of these things as "murky" or unscientific, and, famously, Quine describes talk about propositional attitudes such as beliefs and desires as "second-grade" discourse (Quine 1969: 146), a way of talking that does not properly match anything in the "true and ultimate structure of reality" (1960b: 221). Another example is modality, especially the *de re* part of modal discourse, which involves ascribing possibilities or necessities (essences) to objects. Despite this being a pervasive feature of our talk about the world and understanding of the world, Quine is inclined to be very suspicious of it (1953b, 1953c).

This passage, clearly highlights that the major point of contact between Quine's philosophy and Lewis' one is the methodology as also underlined previously, when it has made clear how Lewis justifies the existence of plural worlds. Apart from this, it is clear that there are irreconcilable points between the two perspectives that inevitably pull them apart.

Conclusion

In this chapter, it is argued that merging Lewis' viewpoint and Quine's perspective to make sense of probability in QM while preserving Quine's naturalism and extensionalism is unfeasible. It is highlighted a deep incompatibility between Lewis' view and the Quinean one. Several aspects have been treated to make this incompatibility clear among those that have been examined, there are Lewis' modal realism, his account of probability, Humean Supervenience, and Lewis' account of dispositions. The discussion highlighted that differences and discrepancies between Quine and Lewis are profound. This makes it impossible to take advantage of Lewis' speculations to solve the issues of Quine's philosophy. This chapter is made of one major section given that Lewis' systems are deeply intertwined and each chunk cannot be analysed separately from the other ones. In Section A.1, it has been examined Lewis' modal realism and his counterpart theory highlighting that Lewis' modal realism is motivated by his extensionalism. This has been considered as an important aspect to account for in this work given that extensionality is one of the main cornerstones Quine aims to maintain. In section A.2, it has been taken into account Lewis' account of probability and inherent drawbacks have been highlighted (i.e., the big bad bug, a major problem with the PP). Given that the PP is closely linked with HS and the distribution of qualities of the Humean base, criticism on this is performed deeply in the paragraphs on HS and laws of nature. In section A.3, I considered Lewis' Best System account of laws of nature highlighting that Lewis' system rules out modality, in particular, metaphysical necessity, from laws of nature that depend on local facts. Moreover, the issue with the PP is treated in the light of Lewis' account of laws of nature in this section. Section A.4 treats HS by examining its general aspects and the constituents of the Humean base, remarking that dispositions are not basic aspects of reality according to Lewis. In this section, there have been also raised arguments against HS. Indeed, QM has disproved HS, which calls for locality. Instead, non-locality and entanglement represent cornerstones of QM with Bell's inequalities that demonstrate HS as it cannot be in accordance with QM. Thus, given that HS is in contrast with physics a major complication arises when its implementation in the Quinean systems is attempted. This complication becomes even more substantial when it is highlighted that dispositions in Quine's speculation have a relationship with physical mechanisms and need to have a place in scientific theories (expressed extensionally, of course). Finally, section A.5, has shown that Lewis does not share with Quine the same type of naturalism.

Despite the fact that various elements of divergence have been taken into account in this chapter, we noticed that the major problematic point that prevents us to use Lewis' solution to save Quine's perspective remains the issue of non-locality treated in A.4. Of all the issues, the most difficult challenge for an attempt to extensionalise QM probabilities using Lewis's framework the issue of non-locality represents the strongest problem. This causes a crucial detachment between the two perspectives with Lewis' viewpoint that cannot address successfully the issues Quine's system faces.

Chapter V: Could we integrate QBism in Quine's philosophy?

This chapter evaluates whether the interpretation of probability offered by Quantum Bayesianism (QBism) could be integrated into Quine's philosophy. As mentioned in Chapter I (section B.3) and Chapter II (sections A.1 and A.2, where a discussion on Quine's arguments for subjective probability and his late abandonment of this position is performed), Quine's preferred subjectivist account of probability seems to be insufficient to describe probability in Quantum Mechanics (QM). Quine acknowledges the issue in the book *Confessions of a Confirmed Extensionalist and Other Essays* (2008). In *Confessions of a Confirmed Extensionalist and Other Essays* (2008), Quine considers that subjective probability, i.e., his favoured view for the majority of his philosophical career, is not in line with QM and proposes an account of propensities seen in an extensional light without further developing this point. Given that it has been argued that Quine's use of propensities cannot be given an adequate extensional interpretation, it is worth returning to the question of subjective probability to consider whether Quine's preferred subjectivist interpretation can after all be adequate for the interpretation of probabilities in QM. This chapter is thus dedicated to examining whether QBism, which defines QM probability in subjectivist terms, could be a way out for Quine. Moreover, it will be considered whether integrating QBism in Quine's philosophy could pave the way to fill the gap left in Quine's philosophy by the lack of a clear perspective of probability in QM. Furthermore, the attempt to integrate QBism in Quine's philosophy will be conducted preserving naturalism and the light of Quine's naturalistic view.

The chapter will be concluded by highlighting that even though QBism supports a subjective account of probability that is in line with Quine's early speculations on subjective probability, it turns out to be inconsistent with Quine's naturalism, and thus, unable to resolve the inherent conflict in Quine's philosophy. Section A of the chapter, is divided in two sub-sections, starting with a reconsideration of Quine's thoughts on subjective probability and naturalism, focusing on the entities he accepts in his ontology. Secondly, the main aspects of QBism will be presented, such as the treatment of the Born Rule, probability, measurement apparatus and measurement outcomes. Also, attention will be given to QBism's ontology, highlighting its minimal character. Finally, consideration will be given to QBism's main advantages and drawbacks, paying attention to the issues of QM that QBism seems to be able to solve and the disadvantages of the QBist perspective considered both in a general framework and in relationship with Quine's philosophy.

Section B, is devoted to demonstrating that QBism cannot be successfully integrated into Quine's philosophy to save the combination of subjective probability and naturalism. This will be done by looking at issues related to the potential implementation of QBism in the Quinean framework from different angles. The discussion will be performed by considering all the problems hinted above one by one and in increasing order: from the less problematic to the most significant ones. In particular, firstly it will be considered how QBism is perceived in the scientific community, what physicists think about the massive attention given to agents in the QBist perspective, and whether QBism could be considered one of the best interpretations of QM [B.1]. In B.2., Quine's interpretation of scientific theories is reconsidered. On the other hand, B.3., treats the theme of mathematics in the QBist perspective indicating whether it is in line with Quine's view and establishing that the QBist perspective is still unclear. The major argument against the implementation of QBism in the Quinean philosophy is performed in section B.4, which investigates the explanatory power of the Born Rule interpreted in the QBist way.

Section A: ***Quine and QBism***

In this section, the combination of subjective probability with naturalism adopted by Quine will be reconsidered. Having Quine's perspective within our reach will allow us to perform a deep comparison between QBism and Quine's account (for a fuller discussion on Quine's subjective probability and naturalism see Chapter I, Chapter II and Chapter III, as mentioned in the introduction of this chapter). In section A, it will be specified that the combination of subjective probability and naturalism is no longer acceptable with the development of QM, and it leads to contradiction. These aspects will be treated in the first part of section A, i.e., sub-section A.1. In subsection A.2, a detailed treatment of QBism will be given, highlighting several aspects of this perspective. Drawing on QBism's main guiding lines, details of the ontological perspective of QBists and QBism's general advantages and drawbacks will be given.

Major drawbacks that could prevent the assimilation of QBism in the Quinean framework will be mentioned at the end of A.2 and will be deepened in section B. Indeed, sub-section A.2 is the foundation of section B, where it will be argued against the integration of QBism perspectives into Quine's philosophical account.

The examination of QBism's cornerstones and its main characteristics turns out to be pivotal to determine whether QBism could be successfully integrated into a Quinean perspective and to what extent Quine would accept this implementation, i.e., whether accordance could be found between the two philosophical accounts to proceed to assimilating elements of QBism in Quine's philosophy.

A.1 ***What are the entities Quine accepts in his ontology?***

Quine talks about probability in *From Stimulus to Science* (1995), where he argues that probability is subjective, i.e., probability expresses the degree of belief in the occurrence of a certain event. Quine does not treat the concept of probability very deeply, but he maintains the idea that a subjective account of probability would suffice for science were it not for the probabilistic nature of QM. Indeed, as we have noted, with QM, he changes his perspective and talks about propensities as shown in *Confessions of a Confirmed Extensionalist and Other Essays* (2008). This latter one has been published posthumously; thus, Quine has not developed his view on propensities further. But for the sake of this chapter, I consider Quine's subjective probability that was backed by Quine for the majority of his career.

Another main aspect of Quine's perspective, as discussed previously in this thesis, is naturalism. Quine takes into account his version of naturalism in 'On What There Is' (1948) where he clarifies his ontological viewpoint too. Indeed, he states that the ontology accepted has to be grounded on our demonstrated scientific theories. Therefore, the *corpus* of our demonstrated scientific theories establish which entities we ought to believe to exist. In Hylton's words (2007) that we ought to accept that all the objects "useful" for the theory of the world exist and no entities are given prior to the theory. As a consequence of this, entities entitled to be part of the Quinean ontology are all and only those quantified over in our best scientific theories, i.e., physical objects and abstract mathematical entities because of the role they play in science. With regards to physical entities, they are composed of the conjunction of bodies and states, while mathematical entities are simply sets, in which numbers and functions are included (*Ibid.*). The two abovementioned categories of entities are accepted because of their utility for our demonstrated scientific theories (*Ibid.*); where being useful for the theory of the world is the main and only principle Quine follows to choose what objects to include in his ontology.

Nevertheless, as (with the experimental confirmation of Bell's results) the fundamentally probabilistic nature of the quantum world became harder to resist, trouble started for Quine's perspective. Indeed, while Quine's naturalism tells us to accept the existence of all the entities taken into account in our theory of the world, Quine's rejection of all types of modalities tells us that probability is subjective; but, QM describes a probabilistic nature. This means that if we commit to Quine's naturalism we need to commit to the existence of objective chance, violating Quine's subjective probability precept. Whether subjective probability and naturalism could be saved together will be a matter of the next paragraphs where I will examine QBism. This to determine whether QBist subjective probability could be implemented in Quine's philosophy to solve its inherent contradiction.

A.2 ***QBism***

Quantum Bayesianism (QBism) is an interpretation of QM in which subjective probability plays a pivotal role. It is a reaction to perceived shortcomings in the Copenhagen interpretation of QM.[11] Indeed, while the Copenhagen interpretation of QM appears to be unclear and mysterious, QBism seeks to clarify QM peculiarities by focusing on the role of agents in physical processes. Specifically, given that agents are seen as observers who participate in the processes that occur in the world (Fuchs, 2018), they have a central role in the experiments performed in QM. Thus, QBists are deeply and mainly focused on the role played by individual knowledge in the QM field. This has a major impact on QBists' treatment of probability. As hinted above, the core cornerstone of QBism is the subjectivist aspect QBists retrieve in the theory of QM, but there is room for objective aspects too. For this reason, it is vital to discern the subjective from the objective in QM. To be more specific, according to one of the founders of QBism, Christopher Fuchs,

11 Fuchs (2018 p. 4) says: "I tried—I tried really, really hard—to find some angle, some way of understanding Bohr and the other Copenhageners that would convince me that they had given a consistent account of quantum theory […] I never got there. Their doctrines just never fully made sense to me".

> The quantum system represents something real and independent of us; the quantum state represents a collection of subjective degrees of belief about something to do with that system (even if only in connection with our experimental kicks to it). The structure called quantum mechanics is about the interplay of these two things—the subjective and the objective. The task before us is to separate the wheat from the chaff. If the quantum state represents subjective information, then how much of its mathematical support structure might be of that same character? Some of it, maybe most of it, but surely not all of it. Our foremost task should be to go to each and every axiom of quantum theory and give it an information theoretic justification if we can. Only when we are finished picking off all the terms (or combinations of terms) that can be interpreted as subjective information will we be in a position to make real progress in quantum foundations. The raw distillate left behind—minuscule though it may be with respect to the full-blown theory—will be our first glimpse of what quantum mechanics is trying to tell us about nature itself. (Fuchs, 2002 p. 5-6.).

Therefore, according to QBism, we notice that QM is a patchwork of subjective and objective aspects that can be reduced to subjective quantum states and objective quantum systems. With regards to quantum states, QBists also want to determine the amount of objective and subjective mathematics that is used to describe a quantum state. With regards to this, QBists claim: “Tempting though it is to grant objective status to all the mathematical objects in a physical theory, there is much to be gained by a careful delineation of the subjective and objective parts” (Caves *et al.*, 2002 p. 4538) . Therefore, through the examination of each mathematical axiom used to describe quantum states, QBists can trace all the subjective parts of mathematics. Once QM is deprived of all the subjective aspects, the rest represents the only real part of QM.

The main guiding lines of QBism can be found in ‘Notwithstanding Bohr, the Reasons for QBism’ (Fuchs, 2018 p. 1 and p.10) and they are as follows:

a) Probability is the degree of belief an agent ascribes to a given outcome of an experiment.
b) The Born rule is fundamental and is normative.

c) Quantum measurement outcomes are just personal experiences.

d) The measurement apparatus is nothing but a tool and also an extension of agents involved in a measurement process.

According to a), probability is the subjective degree of credence attributed to a certain outcome. QBists follow Bruno de Finetti's line of thinking on probability (Healey 2017). Galavotti (1989, p. 241) clarifies de Finetti's perspective in this way:

> probability is defined in terms of betting quotients, namely the degree of probability assigned to a given event by a given individual is to be identified with the betting quotient at which he *would be* ready to bet a certain sum on its occurrence. The fundamental and unique criterion one must obey to avoid sure losses is that of coherence. The individual in question should be thought of as one in a condition to bet whatever sum against any gambler whatsoever, free to choose the betting conditions, like someone holding the bank at a gambling casino. Probability can be defined as the fair betting quotient he would attach to his bets. Coherence is a sufficient condition for the fairness of a betting system, and a behaviour conforming to coherence can be shown to satisfy the principles of probability calculus.

The abovementioned passage highlights two main aspects of de Finetti's viewpoint on probability: the importance of coherence (which occurs when a given belief is in agreement with the probability calculus) and the humans' gambling attitude. To these two aspects, a third one is added by de Finetti, i.e. operationalism, which is a theory according to which "we do not know the meaning of a concept unless we have a method of measurement for it" (Chang 2021). Furthermore, de Finetti combines operationalism with pragmatism (i.e. the philosophical approach in which the applicative aspect of theories plays a pivotal role). Therefore, the combination of pragmatism and operationalism allow de Finetti to adopt an anti-realist perspective on probability, i.e., de Finetti defines probability in a way that allows him to avoid any ontological commitment (Galavotti, 1989). This latter aspect is shared *in toto* by QBists and they apply the radical subjectivist account of probability to QM. To be more specific, Fuchs (2018, p.10) clarifies:

> With regard to quantum probabilities, QBism asserts that they are to be interpreted as genuinely personal, Bayesian degrees of belief. (…) The implications of this are deep, for one can see with the help of quantum information theory that it means that quantum states, too, are not things out in the world. Quantum states rather represent personal accounting, and two agents speaking of the same quantum system may have distinct state assignments for it. In fact, there are potentially as many quantum states for a system as there are agents interested in considering it.

Point a) is connected to b). Indeed, QBists believe that the Born Rule is normative and not descriptive and agents must adhere to the abovementioned rule in their probability and quantum state assignments. While descriptive statements describe the world as it is, normative statements cannot be verified or tested and are grounded on a value judgement on a situation that could be either desirable or not. Therefore, a normative statement is a statement that talks about the world as it should be and not as it is. In the standard interpretation of QM, the Born Rule is an algorithm used to generate probabilities for different outcomes of a given measurement of one or more observables in a quantum system. Healey referring to QM theory explains that “These probabilities have traditionally been regarded as objective, in line with the idea that the theory is irreducibly indeterministic” (Healey, 2017). By contrast, QBists interpret quantum probabilities in a personalist way attributing to human agents a central role in the philosophical speculation. Moreover, since all quantum states are considered as something that merely provides input to the Born Rule, QBists consider quantum state assignments as something subjective, too. Thus, since the quantum states assigned by agents represent their credences, the quantum theory is nothing but a kind of manual that each agent uses as a guide to navigating the uncertainty of our world to make reasonable decisions (*Ibid.*).

According to QBists the Born Rule acts as a coherence requirement with agents, who ought to assign probabilities in alignment with the Born Rule's constraints (Fuchs and Schack 2013). Moreover, according to Fuchs and Schack (2013), the Born Rule should be considered as something empirical (i.e., a statement about our physical world) that is added to the Dutch-Book coherence requirements that are usually taken into account in subjectivist probability perspectives to guarantee that each degree of belief is not branded as incoherent. In other words, QBism combines its normative version of the Born Rule with the traditional Bayesian line of thought.

The Born Rule, as traditionally interpreted in QM, identifies the probability that a measurement will yield a certain outcome given a quantum state. Applying the Born Rule to a radioactive atom can predict successfully the half-life of atoms with radioactive properties. Predictions made by the Born Rule have been confirmed by experiments. For this reason, most physicists believe that probability in QM is objective, i.e., a feature of the world (Healey, 2017). On the contrary, QBists take probability as subjective and they downgrade the Born Rule from a law of nature to a normative statement about how we should update our degrees of belief about our physical world. Also, to avoid incoherence, the QBist perspective requires that each agent align her beliefs to the Born Rule.

Point c) and d) refer to the measurement problem and the measurement apparatus. As already seen, measurement outcomes are just personal experience in the light of QBism and this guarantees to QBists the solution of the measurement problem, a major issue in QM. The measurement problem deals with the wave-function collapse that occurs after humans' observation. Specifically, the wave-function assigned to a physical system and the way it evolves is governed by the Schrödinger equation that is regarded as the complete description of the system, but once the measurement is carried out the dynamics of the wave-function (which evolves deterministically as a linear superposition of different states) is not compatible with the determinate measurement's results (Gao, 2019 p. 300). Thus, physicists are unable to establish how (or whether) the wave function collapse occurs. The solution provided by QBism to this problem deals with the idea that quantum states do not describe their related system as being subjective. Indeed, according to QBism, any agent designates her quantum state considering the available information with the only constraint of coherence. In the light of new experience, the attribution of a given quantum state can change, so that the ‘collapse of the wave function’ is really just the result of the change in information state of the observer. Therefore, as Fuchs and Schack (2013) clarify, every quantum measurement depends on the agent who performs it. Specifically, each quantum measurement is a creative moment where each agent acts on the world and generates something completely new. Therefore, each measurement outcome is personal experience. Moreover, for different agents, we will notice different measurement outcomes linked to the experience they have individually. This has a major impact on how the measurement devices are conceived for QBists. Indeed, also, in this case, the focus is on agents. To clarify, measurement instruments are mere extensions of agents. Therefore, a measurement apparatus should be considered a kind of organ, i.e. both a tool and a part of each agent and this applies to each user of the quantum theory (Fuchs, 2018 p. 21).

In terms of predictions, QBism makes the same probabilistic predictions as standard QM. Marchildon (2015 p. 758) clarifies this by saying that "there are no empirical differences between the probabilistic predictions made by a QBist and the predictions made by someone who claims that the state vector represents the true state of a quantum particle". Indeed, according to QBism, agents assign a state vector or density operator (that depict the probability for any outcome of a measurement on a quantum system for pure or mixed quantum states) to a system and calculates probabilities of the various outcomes of a measurement stemming from their interaction with the system with the Born Rule. Agents update their state vector or density operator when a given outcome has occurred (*Ibid.* p. 756). This means that there is no inherent contradiction in QBism predictions, it is just a matter of preference whether to opt for a subjectivist interpretation of the state vector or not. In the standard view of QM, both the state vector and the density operator are linked to the idea that probabilities are objective. Therefore, the only thing that differentiates QBism from standard QM, is QBism’s philosophical implications.

A.2.1 ***QBist ontology***

All the aspects previously considered have a major impact on QBist ontology.

Indeed, QBist ontology is thin to non-existent. Indeed, as Fuchs (2018) specifies, QBist ontology is based on experience. To be more specific, QBist ontology is "An ontology of all-pervasive, pan-creative experience" Fuchs (2018 p. 32). This means that there is nothing except experience. In 'QBism, FAPP and the Quantum Omelette. (Or, Unscrambling Ontological Problems from Epistemological Solutions in QM)' (2016), De Ronde dissects QBism's ontology noting that QBists do not equip their theory with any kind of ontology. And this is in line with Fuchs' thoughts about the ontological valence of experience previously considered. Moreover, given that QBism is a radical subjectivist view, De Ronde (*Ibid.*) points out that the rejection of ontological relations between QM and physical reality guarantees the consistency of QBism. And, the denial of the ontological dimension is so strong that QBists remain silent on the existence of micro-objects, too. This shows the drastic epistemic attitude adopted by QBists that prefer to avoid even a direct reference to the microscopic objects' dimension to evade the issues of QM ontology. Furthermore, the very denial of an ontological dimension leads QBist to solve some major issues of QM (e.g., non-locality, the measurement problem) making QBism a very coherent viewpoint (*Ibid.*) even though the ontological debate on QM are rejected from the outset (*Ibid.*).

A.2.2 ***Advantages and drawbacks of QBism***

Decoherence, the measurement problem and non-locality are some of the most compelling issues in QM. QBism can overcome all of them. As I mentioned in the previous paragraph, the measurement problem is solved in the QBist context by reducing quantum states to subjective degrees of belief that do not describe objectively a system. Similarly, QBism can avoid the odd consequences of non-locality. Non-locality represents one of the main peculiar consequences of QM. Indeed, it violates the principle of locality, according to which distant objects cannot directly influence their behaviour on each other, being an object directly influenced only by its proximate context. On the contrary, non-locality, which goes hand in hand with quantum entanglement (i.e., when particles that interact become permanently dependent on each other's quantum state, behaving as a single entity), is the objects' attitude of being responsive to each other's state instantaneously, even when separated by large distances and not sharing the same context. QBism seeks to solve the non-locality issue by shifting the focus on agents' personal experiences.

Indeed, as Healey (2017) explains, for QBists science relies on the individual experiences of each agent and not on objective descriptions of physical events. Indeed, an agent is able to experience only events where she is and not events that occur at another location and experienced by another agent (Healey, 2017)

> Correlations taken to manifest non-local influences supposedly concern events in different places—say where Alice is and where Bob is. But Alice can only experience events where she is, not at Bob’s distant location. When she hears Bob’s report of what he experienced at a distant location, this is an experience she has where *she* is, not where Bob reports having had his experience. (*Ibid.*)

In other words, the correlations between particles that seem to demonstrate that there is the non-locality phenomenon and entanglement between the two above mentioned particles, are explained by QBists as correlations that occur among experiences that are spatially coincident and each agent uses quantum theory successfully just to account for their experiences (Healey, 2017). We could notice that this solution to non-locality seems to be a bit quick. In particular, the normative nature of the Born Rule proposed by QBists means that when Alice observes her electron as spin up, she ought to believe that the entangled electron is now spin down. But the question is: why would that be rational if there were not some connection between her measurement of the electron at her end and the state of the far distant electron? More on this rational aspect in relation to the Born Rule is said in B.4.

Also, QBism seems to have its own view on decoherence too, as it will be explained in the next lines. According to the theory of quantum decoherence, the interaction between a quantum system and our macroscopic world determines the fact that we are not able to observe a coherent wave-function in the macroscopic world. With regards to quantum decoherence, Schlosshauer (2019 p. 3) describes it in a very precise way saying that:

> The key insight in addressing the problem of the quantum-to-classical transition was first spelled out almost fifty years ago by Zeh, and it gave birth to the theory of quantum decoherence (...). The insight is that realistic

> quantum systems are never completely isolated from their environment, and that when a quantum system interacts with its environment, it will in general become rapidly and strongly entangled with a large number of environmental degrees of freedom. This entanglement dramatically influences what we can locally observe upon measuring the system (...). In particular, quantum interference effects with respect to certain physical quantities (most notably, “classical” quantities such as position) become effectively suppressed, making them prohibitively difficult to observe in most cases of practical interest.
>
> This, in a nutshell, is the process of decoherence. Stated in general and interpretation-neutral terms, decoherence describes how entangling interactions with the environment influence the statistics of future measurements on the system.(...). In this way, decoherence lies at the heart of the quantum-to-classical transition. It ensures consistency between quantum and classical predictions for systems observed to behave classically. It provides a quantitative, dynamical account of the boundary between quantum and classical physics. In any concrete experimental situation, decoherence theory specifies the physical requirements, both qualitatively and quantitatively, for pushing the quantum–classical boundary toward the quantum realm. Decoherence is a genuinely quantum-mechanical effect (...).
>
> One of the most surprising aspects of the decoherence process is its extreme efficiency, especially for mesoscopic and macroscopic quantum systems. Furthermore, due to the many uncontrollable degrees of freedom of the environment, the dynamically created entanglement between system and environment is usually irreversible for all practical purposes; indeed, this effective irreversibility is a hallmark of decoherence. (...) Advances in experimental techniques have made it possible to observe the gradual action of decoherence in experiments such as cavity QED, matter-wave interferometry, superconducting systems, and ion traps.

As just considered by Schlosshauer (*Ibid.*) decoherence stems from the very idea that quantum systems are not isolated; instead, they interact with the environment. And, decoherence explains the link from the quantum to the classical world accounting for the entangling interactions that occur between quantum systems and our classical world, which influence our measurement on the system. Moreover, decoherence “merely addresses a consistency problem, by explaining how and when the quantum probability distributions approach the classically expected distributions.” (Schlosshauer, *Ibid.*). And, it is worthy to specify that decoherence makes the same prediction of standard QM, it has not been developed in the context of a particular interpretation of QM and stems from using the formalism of QM to interacting quantum systems (Schlosshauer, *Ibid.*). Also, Schlosshauer (2019 p. 4) remarks that decoherence nowadays represents an important topic in QM, which is considered both in a theoretical way and experimentally, as considered above. Moreover, Schlosshauer (2019 pp. 60-61) remarks that Zeh, who firstly talked about decoherence, “observed that decoherence is a normal consequence of interacting quantum mechanical systems. It can hardly be denied to occur—but it cannot explain anything that could not have been explained before.”

The clarificatory observations made on decoherence bring us to the treatment of decoherence proposed by QBists. Specifically, QBists highlight that quantum decoherence can be understood in purely personalist terms. Indeed, they think it is not a physical process and has to do with the so-called reflection principle. Fuchs and Schack (2012 pp. 7-8) explain that the reflection principle is a constraint imposed on agents’ current beliefs regarding their future probability measurements; probabilities that infringe the reflection principle are incoherent. In turn, QBists believe that incoherence should be cleared. This means that the reflection principle is a kind of “tool to detect incoherence” (*Ibid*. p. 10). Therefore, according to QBists, decoherence deals with future measurements on a system. To be clearer, decoherence, which is an implication of the reflection principle, occurs when an agent at present time assigns a coherent state that simulates a belief on a future measurement. Fuchs and Schack (2012 p. 12) specify that decoherence is “simply a quantum state the agent uses at time t= 0 before the first measurement to make decisions regarding the outcomes of the second measurement”.

Therefore, having addressed the issue of decoherence, the measurement problem and non-locality, QBism provides an opportunity to deal with quantum weirdness in a new light and this looks surely advantageous.

But, objections to QBism are around the corner with two main problems QBism should address: anti-realism/instrumentalism and solipsism (i.e., the idea that we cannot know the external world and the only thing we know is our self). With regards to anti-realism, this represents a major issue in comparison with Quine's philosophy, as I will consider later in this chapter. Anti-realism charges against QBism amount to the idea that, according to QBism, science does not truly describe the world as it is. Indeed, QBism looks like a form of instrumentalism, where, according to instrumentalism, scientific theories give us reliable predictions of only things we can observe and the main aim of theories is to cohere with observation.

While there is not a common line of reasoning among the QBist community regarding the anti-realism and instrumentalist issue, some QBists follow the later Fuchs, who prefers to rename his perspective as "participatory realism". Fuchs' "participatory realism" aims to address both solipsism and instrumentalism. Indeed, Fuchs (2016) rejects critics by saying that QBists do not reject reality. Indeed, at page 8 of 'On Participatory Realism' (2016), Fuchs says: "We believe in a world external to ourselves precisely because we find ourselves getting unpredictable kicks (from the world) all the time." Moreover, Fuchs (2016) puts forward the idea that, according to QBism, physics is no more about laws of nature expressed in an impersonal way. Instead, reality has more facets than any third-person viewpoint can apprehend. Therefore, QBism does not deny reality; thus, it should not be charged with anti-realism, instrumentalism and solipsism (*Ibid.*). Rather, QBism offers a realist perspective that recognises that reality involves the perspective of individual observers. In this light, we could say that QBism looks at science as the place where the real external world meets the individual agent.

The issues with QBism that we just noticed are general worries in the physics and philosophy community, but for the purpose of this work a major worry with QBism would be the specific question of what grounds the rationality of using the Born Rule. As said above, the Born Rule in the QBist framework, acts as an additional requirement to the Dutch-Book argument (which has been considered in more detail in Chapter II); in other words, degrees of belief need to conform to the Born Rule to be coherent. But, the usage of the Born Rule seems to be rational in case there are objective chances and the Schrödinger equation measures how the above mentioned objective chances evolve. In this case grounding the predictions of the Born Rule would be rational. But in the QBist case, they do not think that the

Schrödinger equation tracks objective chances; thus, we ask, what reason is there to adopt the normative principle that physicists ought to update their credences in line with the Born Rule?

The normative aspect of the Born Rule is further clarified by DeBrota *et al*. in 'Born's rule as a quantum extension of Bayesian coherence' (2021 pp. 2-3):

> First, we must unpack the meanings of the symbols ρ and {*D j* }[12] in terms of probabilities that the agent assigns to hypothetical experiments and use the resulting expressions to express the Born rule purely as a constraint on the agent's probability assignments; (…) Second, we must unpack the agent's belief that "the system is quantum" in terms of the agent's probability assignments to the hypothetical experiments. Evidently we cannot take this to imply that the agent uses the full-blown structure of quantum theory or the Born rule, for this would commit the error of assuming what we set out to prove. Instead, we must make use of some minimal assumptions about what "quantumness" might mean for the agent's probability assignments. (…) Third, we must show how these minimal assumptions, plus Dutch-book coherence, implies the Born rule. (…) In principle, we could stop there, for if we hold fixed the agent's belief that "the system is quantum" (as represented by our minimal assumptions), then to not use the Born rule would necessarily mean a transgression of Dutch-book coherence.

We will highlight subsequently what grounds the rationality of using the Born Rule. Objective chances are ruled out and this could represent a major issue for QBism. Indeed, believing in objective chances explains why the mathematics adopted in QM works while QBism requires that we trust mathematics without any explanation of why we should expect it to be successful. This latter issue could be regarded as a naturalistic reason to reject QBism. More on the Born Rule will be said in paragraph B.1.1.

12 Here ρ represents the density operator "to describe a quantum system" (DeBrota *et al*., 2021 p. 1) and {*D j* } is the measurement on the system.

Section B: ***Are we able to save Quine’s subjective probability and naturalism introducing QBism in Quine’s philosophy?***

In section B, I argue that the perspective adopted by QBism is not in accordance with the Quinean one, making its implementation impossible in Quine’s philosophy. In subsection B.1, I will highlight how QBism is perceived in the scientific community and that choosing QBism over other interpretations of QM is a matter of philosophical preference. This is a first point of discrepancy between Quine and QBism since Quine believes that it is in science and not in prior philosophy that we need to look at for our ontological commitments. In section B.2, I will look at Quine’s interpretation of scientific theories, highlighting that he believes that science should be interpreted literally. This represents a main issue when we try to implement QBism in Quine’s philosophy because of QBism’s null ontology. Indeed, QBism remains silent regarding the existence of even microscopic particles and this would not be acceptable for Quine. In subsection B.3, I will look at the treatment of mathematics for QBists. It will be highlighted that QBists are not prone to include mathematical formalism elements in their ontology. This is a discrepancy with the Quinean perspective and would be another main obstacle to the application of QBism subjective probability to solve the problematic aspects of Quine’s philosophy. Subsection B.4, is dedicated to the major concern we deal with when trying to implement the QBist perspective in Quine’s philosophy. It will be highlighted that the normative function of the Born Rule runs into problems when we try to explain the compelling reason to adopt it. I conclude the chapter stressing that QBism could not provide any solution for Quine.

B.1 ***QBism a way out for Quine (?)***

The purpose of this chapter is to determine whether QBism could fit well in the Quinean framework to address the non-negligible gap we evaluate in Quine’s treatment of probability in QM. The inclusion of the subjective dimension in the scientific enterprise and the involvement of agents’ mental domain and experience is a cornerstone of QBism, allowing QBism to overcome several difficulties related to

QM. However, a very first observation should be made regarding how average physics would deal with the overwhelming presence of agents' experience in physics. Fuchs in ‘On Participatory Realism’ (2016) specifies that the prevailing line of thought in physics deals with the idea that physics regards impersonal laws of nature and that there is no place for subjectivity in it. Similarly, Khrennikov (2018) highlights that modern physicists are certainly sure that there is no room for agents' mental dimension in physics. This seems to be in line with the study conducted by Schlosshauer, Kofler and Zeilinger (2013) who took a poll on the attitude towards QM interpretations of physicists and philosophers. Indeed, they surveyed a group of 33 physicists, philosophers and mathematicians regarding their thoughts on QM, including questions about the main issues of QM and their favoured interpretation. The poll demonstrates that the majority of the abovementioned scholars (71%) believe that the observer either should not play any role in QM or that even though it is involved by applying formalism, observers play no distinguished physical role. This is in line with other results of the poll according to which 42% of participants adhere to the Copenhagen (i.e., standard) interpretation of QM and just 6% of participants adopt QBism.

A first remark is that if we read these results in a Quinean light we should assume that, although the QBist version of QM is a viable way for those who look at the issue of the ontology posed by QM and want to commit to a minimal ontological framework, QBism itself remains an interpretation of QM, not QM itself. This latter one represents one of our demonstrated theories of physics that according to Quine’s framework tell us what exists.

Indeed, following Quine's naturalism, our best confirmed theories of science should be taken to be true and determine our ontology. Quine allows for the possibility that our best scientific theories could be false, but he thinks that we ought to believe that they are true (at least until a better theory comes along).This means that in case QBist QM turns out to be the best way of intending QM we ought to adhere to it. In the Quinean sense one’s ontology is represented by the set of entities presupposed by a given demonstrated theory of science, so it is fair to think that Quine’s own ontology was the set of entities presupposed by the best scientific theory of Quine’s time. We cannot establish for sure which theory Quine would have adopted as the basis of his ontology nowadays, but we can try to understand whether QBism would be a plausible candidate.

Quine

> denies that there is a distinctively philosophical standpoint, which might, for example, allow philosophical reflection to prescribe standards to science as a whole. He holds that all of our attempts at knowledge are subject to those standards of evidence and justification which are most explicitly displayed, and most successfully implemented, in the natural sciences […] In Quine's view, philosophers can, therefore, do no better than to adopt the standpoint of the best available knowledge, i.e. science […] Philosophers are thus to be constrained by scientific standards. In (1974) he puts it this way: "In our account of how science might be acquired we do not try to justify science by some prior and firmer philosophy, but neither are we to maintain less than scientific standards. Evidence must regularly be sought in external objects, out where observers can jointly observe it...." (1974, 34f.) (Hylton and Kemp, 2020)

This quote clearly states that there is no prior philosophy, as also underlined by Quine (1981 p. 21) who specifies that "it is within science itself, and not in some prior philosophy, that reality is to be identified and described" and that when we build our knowledge we should adhere to the standards of demonstrated natural science in terms of evidence and validity. This leads me to consider two aspects of a potential implementation of QBism in Quine's philosophy. First of all, the formalism used for QBism and standard QM is the same since they are grounded on the same mathematics. This means that how we interpret the role of agents and the importance of personal experience is a matter of philosophy only. Philosophy, according to Quine, needs to be in continuous with science and be informed by it, rather than independent of it. Whether the case of the philosophical speculations of QBism are informed by science and in continuous with it or not will be a matter of the next pages. Anyway, Hylton and Kemp (2020) highlight that Quine argues that "all of our attempts at knowledge are subject to those standards of evidence and justification which are most explicitly displayed, and most successfully implemented, in the natural sciences".

According to the poll by Schlosshauer, Kofler and Zeilinger (2013) it seems that

QBism interpretation is neither the most successfully implemented in QM nor the most explicitly displayed being a minor interpretation of QM. Furthermore, QBism shares the same formalism of QM, this means that it relies on the same mathematics; thus, shares the same standards of evidence and justification. This leads us again to the idea that QBism is just a philosophical interpretation that emphasises the role of agents in QM, which seems to have less response than other QM interpretations in the physics and philosophy community. In order to evaluate a major problem with QBism, we need to consider the explanatory lacuna in QBists' understanding of the Born rule. Realism about propensities / dispositions / QM probabilities makes application of the Born rule for prediction rational, but if one do not think that the probabilities in the mathematics of QM correspond to objective chances then a lack in explanation of why we should conform our credences to the Born rule is appraised.The above mentioned line of thought will be pursued properly and deeply in B.4.

B.2 ***Interpretation of scientific theories***

Once we established that in terms of formalism there is no difference between standard QM and QBism; and that we cannot define QBism as one of our best scientific theories because it is only a matter of our philosophical preference to adopt one interpretation over another, we could underline that QBism cannot be implemented in Quine's philosophy for an additional reason: i.e., QBist ontology. We have noticed above that QBism remains almost silent about ontology. The same cannot be said for Quine, who is driven by the idea that our best science tells us what exists. Quine's ontology is made of physical objects and abstract mathematical entities. Both physical entities and mathematical ones have a role in QM. The role of formalism is recognised by QBism too, since it adopts the same mathematics of standard QM. On the contrary, the existence of micro-objects in QM plays a secondary and negligible role in QBism, since QBists focus their entire attention on personal experience and remain mostly silent on them. I think that Quine would have not remained silent about the existence of microscopic particles to save subjective probability. Indeed, being microscopic objects (and probability too) incorporated in QM, Quine would have accepted them in his ontology. This seems to be demonstrated by the fact that Quine changed his viewpoint on probability in

Confessions of a Confirmed Extensionalist and Other Essays (2008). Moreover, Pils (2020 p. 613) notices that, according to Quine's viewpoint, "scientific theories have to be interpreted literally. Statements proposing entities in scientific theories should be understood as having truth values. A theory is committed to all the entities that have to exist in order for the theory to be true".

B.3 ***Analysing mathematics***

As mentioned in the introduction to section B, QBists' perspective on mathematics is a peculiar one and more needs to be done to understand whether it could be reconciled with Quine's perspective. First of all, some of the mathematical structures used to support given quantum states seem to be subjective for QBists. To be more specific, QBists do not believe that mathematics simply represents degrees of belief. Instead, QBists insist that there are some mathematical objects and rules in quantum theory that are subjective. Among those, Fuchs identifies quantum states, time evolution operators and measurement operators. These three mathematical entities are subjective for QBists and are of the same character of any Bayesian probability.

In a private correspondence with Fuchs[13], it has been asked whether QBists believe that mathematics is subjective in their viewpoint or, alternatively, elements of mathematics are deemed to be subjective. The purpose of the private correspondence exchange with Fuchs was to understand whether Fuch's point is that the features described by quantum states and the other mathematical objects interpreted in a subjectivist way are intended subjectively or mathematics itself is subjective for QBists. Partly, Fuchs cleared the doubts saying:

> "I didn't mean that mathematics itself is subjective (though it might be at some deep enough level). I was only referring to the various mathematical objects and rules within quantum theory: quantum states, time evolution operators, measurement operators, the tensor product rule for combining systems, the Born rule for calculating probabilities, etc. Over the course of the development of QBism, the first three in that list definitely became to be understood as subjective as they were of the character of any Bayesian probabilities. On the

13 Correspondence took place in 2021, and I was kindly granted permission to consider it in my thesis by Prof Fuchs.

> other hand, the Born rule came to be understood as an invariant scheme across all agents who practice quantum theory (thus a kind of “objective” component), and therefore we QBists have been trying to draw an ontological lesson from its particular structure.”

Here, it can be noticed that, according to Fuchs, a) there are mathematical objects and rules within the quantum theory that are interpreted in a subjectivist way, leading to think that parts of quantum theory formalism is subjective and b) the Born Rule is considered as a scheme used by all the quantum theory scholars. Given that the Born Rule is an invariant device it seems to be objective. Here, objectivity seems to be used as a synonym with invariant. So, the fact that the Born Rule is used by all the practitioners of quantum theory and that all of them use it as a stable, constant device that remains unchanged makes it objective. Objectivity in the case of the Born Rule has nothing to do with objective probability. More on the Born Rule will be said in the next subsection.

It has been said that Fuchs clarified the doubts regarding mathematics in a partial way only. Indeed, while from the correspondence it is impossible to extract a clear and linear perspective on the potential subjectivity of mathematics, it only appears very sharply that there are subjective objects and rules in the mathematics of QM.

According to a study conducted by Stacey (2019) on the ideas QBism abandoned during the years, from its early days to the present, it is clear that QBism wants to find in the quantum theory an ontological framework but does not want to populate its ontology with elements of the mathematical formalism (p. 11). On the one hand, we can appraise that saying that elements of mathematics are subjective does not commit ourselves to think that mathematics itself is subjective, but on the other hand, this viewpoint cannot be shared by Quine given the fact that he believes that abstract mathematical objects exist because of their role in the theory of the world. The Indispensability Argument attributed to Quine and Putnam and revisited by Colyvan (2019) states that: "(P1) We ought to have ontological commitment to all and only the entities that are indispensable to our best scientific theories. (P2) Mathematical entities are indispensable to our best scientific theories. (C) We ought to have ontological commitment to mathematical entities."

Moreover, Colyvan (2019) says:

> Confirmational holism is the view that theories are confirmed or disconfirmed as wholes (Quine 1980b, p. 41). So, if a theory is *confirmed* by empirical findings, the *whole* theory is confirmed. In particular, whatever mathematics is made use of in the theory is also confirmed (Quine 1976, pp. 120–122). Furthermore, it is the same evidence that is appealed to in justifying belief in the mathematical components of the theory that is appealed to in justifying the empirical portion of the theory (if indeed the empirical can be separated from the mathematical at all). Naturalism and holism taken together then justify P1. Roughly, naturalism gives us the "only" and holism gives us the "all" in P1. (Colyvan, 2019)

Also, Colyvan (*Ibid.*) adds:

> These issues naturally prompt the question of *how much* mathematics is indispensable (and hence how much mathematics carries ontological commitment). It seems that the indispensability argument only justifies belief in enough mathematics to serve the needs of science. (Colyvan, 2019)

The needs of science remain the main focus for Quine and all the mathematics useful to science exist. The mathematics used is not recreational, i.e. without ontological status in Quine's framework. Instead it is indispensable due to the role played in QM. The main question of this paragraph has been whether QBists think that mathematics itself is subjective or their point is that the features described by these mathematical objects are subjective, not that mathematics itself is subjective. Vagueness emerges from private correspondence with Fuchs, who says that his aim is not to say that mathematics is subjective but at the same time hints that it could be at some level.

Setting aside this issue, in either case we notice that:

a) according to Fuchs some mathematical objects and rules within quantum theory are subjective
b) QBism does not want to populate the ontology of the quantum theory with the elements of mathematical formalism
c) all the mathematics useful for science and that serves "the needs of science", as Colyvan (2019) puts it, is indispensable for Quine and we should be ontologically committed to it.

These three points highlight an additional point difference between QBism and Quine. The above mentioned difference adds to the issue of the normative aspect of the Born Rule, which will be considered in the next lines.

B.4 ***The Born Rule. Why should we conform our beliefs to it?***

One of the main issues with QBism has been suggested above and deals with the normative aspect of the Born Rule. Current best science supports objective propensities as seen when it has been considered e.g. the case of radioactive atoms decays (which are discussed in more detail in Chapter III). Realism about QM probabilities makes application of the Born rule for prediction rational, but if we do not think that the probabilities in the mathematics of QM correspond to objective chances, then we lack an explanation of why we should conform our credences to the Born rule. Thus it appears that there is an explanatory lacuna in the QBist understanding of the Born rule. First of all we notice that the only objective ground upon which is founded the Born Rule is the fact that it is an invariant scheme adopted by all physicists regularly as it has been considered in B.3. Secondly, the Born Rule needs to be explored in a deeper way.

QBists say:

> The Born rule is a centerpiece of quantum mechanics. The way the Born rule is often described in textbooks is as follows: We presuppose a density operator ρ to describe a quantum system and a positive-operator-valued measure (POVM) {Dj} with outcomes j ∈ {1,...,J} to describe a measurement on the system. The probability q(j) for outcome j is then given by,
>
> $$q(j) = \mathrm{tr}[\rho D_j] .$$
>
> But how do we know which operator ρ and which POVM {Dj } to use in a given experiment? A commonplace view is that once the system and its method of preparation have been specified, there is in principle a uniquely correct choice of ρ that provides the best possible description of the real state of the system. Similarly, it is thought that a unique POVM {Dj } exists in principle, which correctly describes the measuring apparatus.

> *Despite being the common attitude, this interpretation does not stand up to serious scrutiny. For an investigation into the meaning of the symbols ρ and {Dj} leads us into the long-standing measurement problem, which in turn leads to competing interpretations of quantum theory. Most debate focuses on the interpretation of the quantum state ρ, and asks whether the quantum state completely describes reality or represents only a partial description of reality.*
>
> The radical possibility that the particular quantum- state assignment has nothing to do with an agent- independent reality is the core idea of the quantum interpretation known as QBism. (DeBrota *et al.,* 2021 p. 1, my emphasis)

DeBrota *et al*. (*Ibid*.) here provide a brief explanation of the Born Rule as usually intended and highlight that QBism is critical towards the common understanding of the Born Rule, which runs into the measurement problem. It is also highlighted here that with the measurement problem in mind, QBists develop their theory according to which quantum states are not to be considered as descriptions of an objective, observer-independent reality. Examining the density operator that represents the quantum state and the probability resulting from the measurement, they interpret them in a subjectivist way.

DeBrota *et al.* (2021 p. 1) explain how they detach quantum state assignments from the idea that they represent an observer-independent reality, saying that:

> To understand the Born rule from this point of view, we begin by suspending our usual tendency to interpret the symbols ρ and {Dj} as descriptors of a system and the measuring apparatus, and instead see them as they are most directly presented to us: as mathematical symbols, written in ink on a page or in pixels on a laptop screen, that we use for some purpose. This shift in view-point entails that we do not immediately leap to some conclusion about what it is that the symbols mean— rather, we must slowly and cautiously approach their real meaning by adopting a new attitude towards them, in which their mathematical form is not to be assumed but must be derived by a careful consideration of the symbols' purpose. With this in mind, we refocus our attention on what these symbols are used for by the physicist.

Some first concerns about whether Quine's perspective is in accordance with QBism emerge from this quote. There are four main focus points here:

> a)mathematical symbols for the density operator and the measurement on the system do not describe the system
>
> b) mathematical symbols ρ and {Dj} are interpreted as just symbols, characters, icons that are used for a purpose
>
> c) mathematical symbols' real meaning emerges from their purpose in science.
>
> d) QBists' attention is just on what given mathematical characters are used for by scientists.

Making use of Colyvan's discussion in 'Mathematical Recreation Versus Mathematical Knowledge' (2007), we come back for a moment to mathematics since it has been considered in DeBrota's quote (2021 p. 1).

Colyvan (2007 p. 109) considers that:

> According to Quine's version of empiricism, mathematics is empirical in the sense that the truth of mathematics is confirmed by its applications in empirical science. More precisely, Quine argues that when we empirically confirm a scientific theory, we empirically confirm the whole theory, including whatever mathematics is used. (…) Quine is invoking the applications as a reason for taking the mathematics to be true. Moreover, according to this Quinean picture, mathematics is taken at face value—it's about mathematical entities such as numbers, functions, sets and the like—and these entities are taken to exist because of the indispensable role they play in our best scientific theories. This argument has become known as the indispensability argument. (Colyvan 2007, p. 109)

We see from both the quotes that Quine would have, with high probability, rejected this way of interpreting the mathematics of the Born Rule as proposed by QBists. Indeed, it is evident that the two positions, i.e., Quine's one and QBism reach opposite conclusions. On the one hand, Quine says that the applications of mathematics in science give us reason to believe it to be true; on the other hand, QBists similarly focus on the applications of mathematics in science, but they only pay attention to what mathematical symbols are used for and their purpose in science, downgrading them as mere symbols. This issue is somehow connected to what is being said in the next lines.

Indeed, turning to the issue of the lack of explanatory power we come back to the normative role of the Born Rule. It has been said above that the only reason whereby one should conform her beliefs to the Born Rule deals with coherence.

In order to explain the role of the Born Rule, QBists talk about the principle of the Dutch-Book coherence specifying that:

> Constraints on an agent's probability assignments derived from Dutch-book coherence are called *normative* constraints, to emphasize that no law of nature forces an agent to adhere to them. So it is with the rules of the probability calculus: No law forces us to obey them, but we ignore them at our own risk. We shall use the principle here to prove that a decision- making agent (like the physicist in our example) who believes a system to be "quantum" must then assign probabilities $q(j)$ in accordance with the Born rule through some choice of ρ and $\{D_j\}$, or else be vulnerable to a Dutch book. This then establishes the Born rule itself as a normative rule, which an agent should use in addition to the rules of the standard probability calculus whenever they are dealing with quantum systems. (DeBrota *et al*. 2021 p. 2)

Moreover, DeBrota *et al*. (*Ibid*.) explain the process that occurs from beliefs to probabilities, arguing that:

> After this unpacking of beliefs into probabilities and then into wagers, the next step is to check for the existence of a *Dutch book*: a series of wagers, each justifiable on the basis of some belief, but whose totality amounts to a certain loss of money regardless of which outcomes actually occur. If the agent finds that such a Dutch book can be made against them, they may conclude that their beliefs are mutually inconsistent, and can proceed to revise them. This assertion—that a Dutch book implies inconsistency— is called the principle of *Dutch-book coherence*. It depends on the idea that an agent would not *want* to lose money. That is, it connects the abstract idea of "inconsistency" with the concrete and meaningful consequence of "losing money."

This quote, which precedes the previous one in the original article, demonstrates that the adherence to the Born Rule by physicists is just a matter of coherence. Indeed, it is pertinently specified that, as occurs for the probability calculus, in the case of the Born Rule there are no laws of nature that prescribe us to obey to the Born Rule but in case we do not obey to it we do it at our own risk. If a physicist does not obey the Born Rule she would run into a Dutch Book; thus, incoherence. In the light of this, we notice that the Born Rule is just an addition to the rules of probability calculus when we deal with the quantum world. The idea that there is no natural force behind the Born Rule is underlined by DeBrota *et al.* (*Ibid.*) words, when they say that there are no laws of nature and external forces that compel us to adhere to coherence.

Whether QBists are able to show that if one does not obey the Born Rule runs into a Dutch Book and thus that the normative view of the Born Rule is rationally supported is a matter of the next lines. First of all Glick (2021) highlights that QBists normative claims do not follow from a portrayal of the external world since QBism is not descriptive. Glick (2021 p. 53) asks:

> QBism maintains that the significance of the Born rule—formulated purely in terms of subjective probabilities—is to tell us what we have reason to do. (...) How, without providing a description of the world, can we say that we have reason to do what the Born rule prescribes? (*Ibid.*)

After the treatment of the Born Rule seen as an addition to the Dutch Book argument, Glick (2021) underlines that QBists take the Born Rule on a par as the axioms of probability theory intended in subjectivist terms, with the Born Rule that act as a coherence requirement. But Glick (2021) also underlines that there is a fundamental difference between the traditional Dutch Book argument and a quantum Dutch Book argument such as the one proposed by QBists, since the quantum one would have a link with our world instead of requiring only logic and mathematics as the standard Dutch Book.

> The quantum Dutch book applies only in a world relevantly similar to ours—one in which quantum theory provides a good guide for agents in it. But what is it about our world that makes the Born rule the objectively correct coherence constraint? QBists have two sorts of replies to this question. First, they may leave this as a brute feature of reality. That the Born rule acts as a coherence constraint is the limit of what we can say about the world. As Fuchs says, it is “nature’s whisper”. Sometimes QBists express a desire to say more,

> but note that QBism is an active research project, and as such, does not have all of the answers at present. So, a second approach is to seek out the features of our world that necessitate the use of the Born rule. One way to do this would be to derive the Born rule from logic and mathematics supplemented with a minimal empirical claim. However, it's hard to see what resources the QBist has at their disposal for this task. (...) At present, then, QBism must rest content with the first approach: it is a brute fact that the Born rule acts as a coherence constraint. (...) Now, one may wish to know *why* the Born rule acts as a coherence constraint in our world and, for the moment, there is very little the QBist can say here. But, again, this is unsurprising given that QBism rejects the idea that quantum theory functions as a description of reality. (Glick, 2021)

As just Glick (2021) considers, there seems to be no rationality grounding the Born Rule nor do we find a satisfactory explanation of why we should conform our credences to the Born Rule. As Glick (*Ibid.*) argues there is no explanation that accounts for the reason why the Born Rule acts as a coherence constraint - this is left as brute. According to this, there is a lack of explanatory power for the account of the Born Rule in QBism, unlike in standard QM where the use of the Born Rule is explained as grounded in objective chance.

On the other hand, at a first sight, this shows that QBist subjective interpretation seems to be a more convoluted one than the standard way of understanding the probabilities provided by the Born Rule, which relates probabilities to objective chances. And, the naturalistic concern towards QBism is left standing. Again, while relying on the idea that there are objective chances explains why the QM mathematics works, opting for QBism requires we are trustful in the mathematics with no explanation of why we should expect it to be successful.

Now, looking at the issue of theory choice and explanatory power in Quine's philosophy, we rely again on Colyvan's 'Mathematical Recreation Versus Mathematical Knowledge' (2007 p. 111).

> Once the challenge is put this way, we see that Quine has already answered it: we justify our system of beliefs by testing them against empirical evidence and making sure that they satisfy other more pragmatic constraints. No

> distinction is made between mathematical beliefs and other beliefs. Our beliefs form a package that performs well against the usual standards of theory choice and that's all that matters. Any challenge to provide an account of only the mathematical beliefs is again illegitimate. According to the holist, mathematical beliefs are justified in exactly the same way as other beliefs: by their role in our best scientific theories and these, in turn, *are justified by appeal to the usual criteria of theory choice (empirical adequacy, simplicity, explanatory power, and so on).* (my emphasis)

Here, Colyvan looks at Quine's philosophy and talks about the theory choice mentioning amongst the criteria for theory choice empirical adequacy, simplicity and explanatory power. More on this can be found in Orenstein's 'Quine, Willard Van Orman' (2016) where it is specified that:

> Quine's empiricism, by contrast, takes account of the theoretical as well as the observational facets of science. The unit of empirical significance is not simple impressions (ideas) or even isolated individual observation sentences, but systems of beliefs. The broad theoretical constraints for choice between theories, such as explanatory power, parsimony, precision and so on, are foremost in this empiricism. He is a fallibilist, since he holds that each individual belief in a system is in principle revisable. Quine proposes a new conception of observation sentences, a naturalized account of our knowledge of the external world, including a rejection of a priori knowledge, and he extends the same empiricist and fallibilist account to our knowledge of logic and mathematics. (Orenstein, 2016)

More on Quine's viewpoint on explanation can be retrieved in Quine's words. Specifically, Quine and Ullian talk about explanation in *The Web of Belief* (1978). Interestingly in the ninth chapter of the above mentioned work Quine and Ullian talk about the role of explanations. In the first line of the chapter, the above mentioned authors immediately clarify that "The immediate utility of a good hypothesis is as an aid to prediction" (Quine and Ullian, 1978 p. 65). Subsequently, Quine and Ullian define what makes an explanation the best one. Indeed, making the example of tribesmen, who, observing the tides and the position of the moon, formulate potential laws on this, Quine and Ullian focus on explanation and clarify that an explanation is the best one if it answers the question *why* a phenomenon occurs (in this case the authors refer to why the moon is able to affect tides) (Quine and Ullian, 1978 p. 66).The idea that a successful explanation needs to answer to the question *why* regarding a phenomenon is taken again into account by Quine and Ullian with the example of opium and its sedative and hypnotic effect; indeed, they consider that explanation do neither simply require a restatement of the theme that is going to be explained nor the implication of more notions on a phenomenon (1978 p. 67). Therefore, if we say that opium is extracted by poppy flowers we are implying more notions on the phenomenon but it is not by saying this that we are able to explain *why* it is able to induce sleep (*Ibid.*). Furthermore, Quine and Ullian state the importance of explanations arguing that:

> Explanation can be an important means of supporting a hypothesis. Confirmation of a hypothesis consists in verifying its consequences, but we do well also to look in the other direction and consider what could imply the hypothesis. For the hypothesis inherits the full support of any belief that implies it. Thus it is wise and customary to seek explanation not only for what we already believe true, but also for unproved hypotheses. We are rightly wary of beliefs for which no explanation could be envisaged (1978 p. 72).

Turning our attention to QBism again and focusing on its explanatory power it seems that it has not a satisfactory explanation of why the Born rule works, since it is not backed by objective chances or anything else except for their appeal to coherence, which remains unexplained anyway.

Gründler (2016) says:

> If we follow the QBism interpretation, then the mathematical result helps us to update our personal believes [sic] and informs us, which bets we should accept, and which bets we better should reject, 'and that's all there is to it.' With other interpretations, which consider the state function as representing something 'out there', we get a much richer picture: We see electrons, which can (or can not) due to an externally applied voltage and/or interactions with phonons be excited into a free energy level, and then move almost unimpeded through the solid. No such pictures exist with QBism, because in

> that interpretation the state function does not represent anything ‘out there’ (pp. 9-10)

Thus, Gründler (2016) underlines that no picture of what exists can be derived from QBism. Surely opting for either picture of reality is a matter of preference but this gives once more an idea of the ontology connected with QBism.

Furthermore, Gründler (2016) supports the idea that the explanatory power of QBism is poor, arguing that:

> Caves, Fuchs, and Schack may rightly claim that they unscrambled the egg, at least with regard to the interpretation of the state function. They purged it from all objective content (Heisenberg’s Aristotelian tendencies out there, Bohr’s objective individuality of quantum phenomena), and kept nothing but the subjective believes [sic] of an agent. But this success comes at a high price: At the same time, they skipped a large part of the explanatory metaphysical power of the Copenhagen interpretation, without replacing it by anything better. (...) QBism, however, simply amputated the objective part from the interpretation of the state function (while keeping with no modification the full mathematical machinery with it’s ‘scrambled objective and subjective elements’), and left us with a torso of marginal explanatory power, a bridge with only one head on one bank. (Gründler, 2016 pp. 11-12)

Gründler (*Ibid.*) observations on a marginal explanatory power proposed by QBists seem to be supported also by QBism itself. The article ‘FAQBism’ (DeBrota and Stacey, 2019) is devoted to clarify a number of questions QBists usually face. Among the above mentioned questions, we find an inquiry about the explanatory power of QBism. This is a general question focusing on the explanatory power of QBism as a whole, and does not deal specifically with the Born Rule issue, which remains the main problem with the explanatory power of QBism. Anyway, regarding the general explanatory power of the theory which remains a concern when we talk about QBism, QBists say that QBism does not lose the explanatory power of the other interpretations of QM if we stand for “*a reasonable notion of “explanation””* (DeBrota and Stacey, 2019 p. 3). In particular they say that explanation should deal with the role of agents in physics. Indeed it seems QBists say that explanations are not isolated statements. On the contrary, we need to consider the aspect of intervention on a physical system. In particular, taking into account the example of words like "*solid* and *rigid* and *incompressible,* we are, at least tacitly, making claims about how a physical system will react against interventions" (DeBrota and Stacey, 2019 p. 27). This leads QBists to think that agenthood is always present even in other fields of physics such as the solid-state mechanics (*Ibid*.). Plus,

> The fact that we do not make single predictions in isolation is ultimately baked into the formalism, because asserting a quantum state assignment ρ for a system implies quantitative expectations about the outcomes of *any* experiment that one can represent in the theory. No expectation value stands alone (DeBrota and Stacey, 2019 p. 27)

These considerations help us to get a clearer picture of what explanatory power means in the QBist perspective and how the Quinean and QBist perspective detach in respect of explanations with Quine focusing on the *why* a phenomenon occurs. The *why* aspect is missing in QBism with regards to the Born Rule. We still cannot know *why* we should conform our beliefs to the Born Rule in a QBist framework.

Therefore, we notice that explanatory power has a huge weight for theory choice for Quine, but explanatory power is poorer with QBism than the standard interpretation of QM with respect to the use of the Born Rule. We guess that this would have been a major problem that prevented Quine from relying on QBism. Therefore, all the issues considered in this paragraph added to the other ones mentioned throughout the chapter lead us to think that we cannot attempt a successful implementation of QBism into Quine's philosophy.

Conclusion

This chapter investigates QBism and motivates the reasons why QBism cannot be considered a way to solve the inherent issues of Quine's philosophical account evaluated elsewhere in this thesis. In particular, given the fact that Quine's perspective on probability faces major problems if compared with the type of probability proposed by QM, it has been considered whether QBism offers a potential way out for Quine. To be more specific, QBism promotes subjective probability, a type of probability supported and endorsed by Quine as well, given that only a posthumous article by Quine, i.e., *Confessions of a Confirmed Extensionalist* (2008), shows a shift in the Quinean speculation towards the propensity view of probability. We considered the above mentioned change of perspective in the other chapters of this thesis. With regards to this chapter of this work, it has been shown that QBism cannot be applied to Quine's account to solve its aspects of incoherence because of the incompatibility between Quine's ontological framework linked to his naturalism and the QBist one and, most importantly due to the lack of explanatory power of the normative version of the Born Rule proposed by QBists.

To support these conclusions, the first part of the chapter has been devoted to Quine's ontology and naturalism. Indeed, this phase of Chapter V has been dedicated to enrich and detail in a deeper way notions treated in previous chapters of this work such as the entities accepted in the Quinean ontology. In particular, the themes deepened in A.1, provide a basis for further discussion performed in section B of Chapter V. After that, QBism has been taken into consideration, with its general characters [A.2], ontology [A.2.1] and advantages and drawbacks too [A.2.2]. Moreover, while general drawbacks in the philosophy and physics community have been evaluated in order to highlight the weaknesses of QBism *per se* and without reference to the Quinean perspective, a part of A.2.2, is committed to hinting a fragile point in the QBist system brought out in relation to Quine's philosophy. Further discussion on the above mentioned point is considered in section B.4.

Subsequently, I took into account general consideration about how QBism is perceived in the physics and philosophy community by evaluating a poll's results conducted by Schlosshauer, Kofler and Zeilinger (2013). This to determine how QBism is perceived among physicists and philosophers and whether it is considered a way of interpreting QM that is generally found attractive, if it can effectively rival the other interpretations of QM, and if its cornerstones are viable for scholars [B.1].

After that, the discussion focused on one of the two main worrying characteristics of QBism that seem to prevent its usage in support of the Quinean philosophy. In particular, the topics treated in subsection B.2, are deeply intertwined with the arguments of subsection B.3. Specifically, firstly it has been considered how scientific theories according to QBism and this has been compared with the Quinean interpretation of scientific theories [B.2]. Secondly, it has been reconsidered again the QBist ontology. As seen in subsection A.2.1 of the chapter, the ontology proposed by QBists is very meagre, and it seems to exclude some mathematical entities. Given Quine’s attention to the role of mathematics in the scientific theories and his well known platonism, subsection B.3., aims to make clear whether for QBists mathematics is subjective or if the subjective aspect deals with the features described by mathematics. The result of this investigation leads us to think that while it is not in the plans of QBists to say that mathematics itself is subjective they do not entirely rule out the possibility that it could be at a deep level. Drawing on this result, it has been observed that this position would have probably made Quine at least uncomfortable [B.3]. After that, subsection B.4, has been devoted to the main issue we deal with if we try to implement QBism into the Quinean philosophy, i.e., the lack of explanatory power of the Born Rule. Indeed, it has been evaluated that QBism has its own major explanatory gap and it is unable to motivate why we should conform our beliefs to the Born Rule. We notice that the above mentioned issue speaks against QBism nevertheless [B.4].

In conclusion, this chapter highlighted that there are major discrepancies between the QBist perspective and the Quinean one and it underlined and made clear the reasons why QBism is not a feasible way to save Quine's account of subjective probability in QM.

Conclusion

This thesis argues that Quine's perspective on probability and the combination of naturalism and extensionalism he proposes runs into incoherence in the light of developments in Quantum Mechanics (QM) which appear to support the idea that nature is objectively probabilistic. It builds on the insight that probability in QM cannot be seen in an extensional light as proposed by Quine, and it is noted that this jeopardises the chances of success of Quine's conjunction of extensionalism plus naturalism. To be more specific, extensionality represents one of the cornerstones of Quine's perspective, with Quine devoting his entire philosophical speculation to extensionality and putting it in the foreground throughout his system. Quine's extensional standpoint is combined with naturalism, with Quine supporting the thesis that our best scientific theories determine what exists. In other words, according to Quine, our ontological framework is based on science. This implies a specific ontological dimension where the entities allowed are posited by science. In accordance with his extensional perspective, Quine proposes two different accounts of probability developed in different moments of his philosophical career. While Quine's first account of probability, which characterised his speculation for the majority of the time, supports the idea that probability is subjective, Quine's subsequent perspective on probability, which appeared in the last years of his career, advances the idea that probability should be read in terms of propensity; thus, in an objective way. This latter account of probability is motivated by the advancements in the QM field. Thus a shift from subjective probability to propensity is appraised in the Quinean speculation. The propensities Quine takes into account are of a special kind since they should be read in an extensional light. Unfortunately, this point has not been deepened further and Quine did not provide neither a complete nor a fuller discussion on the theme. Nevertheless, it can be noticed that Quine’s aim in adopting the propensity interpretation of QM probabilities is that extensionalism is still preserved; as well as the combination of extensionalism and naturalism. In the light of all of this, we notice that Quine's naturalistic position and extensionalism are complicated with the QM treatment of probability that poses important challenges to Quine's perspective.

Thus, this thesis sheds light on a major issue the Quinean philosophy suffers from by a) unearthing the above mentioned problem and appraising it, and b) arguing that solving this issue while preserving both extensionalism and naturalism, is unfeasible.

The thesis builds on Quine's philosophical perspective, with particular regard to Quine's anti-modalism and naturalism, and the role of probability in QM. It proceeds to unveil the problematic aspect of the Quinean philosophy in relation to QM and it develops by showing that the problem cannot be solved without dropping key features of the Quinean system.

In Ch. I, Quine's scepticism towards modality was taken into account. Prior to delving into the Quinean arguments on modality, the discussion started with a few remarks on probability in QM to introduce the reader gently into the argument of the thesis [Ch. I/A]. Subsequently, a review of Quine's philosophical cornerstones was performed focusing on modality on the logical side, since Quine devoted a large part of his works to this discussion. It was highlighted that Quine's main aim is to use first-order logic, an extensional type of language, to express scientific theories. Plus, this chapter included a treatment of Quinean naturalism, i.e., the thesis according to which our best science prescribes what we ought to believe exists. Moreover, it was noted that the Quinean treatment of logical modality is strictly linked to his ontological perspective, given that the use of first-order logic for scientific theories which provides a pure extensional framework is connected with the idea that our best scientific theories tell us what exists. It was emphasised that modal expressions are either rejected or extensionalised in a pure Quinean framework. Indeed, Quine evaluates the idea that there are three degrees of modal involvement. The first and second degrees of modal involvement are easily solvable as they can be extensionalized. On the contrary, the third grade of modal involvement is considered to be much more problematic since it cannot be extensionalised. Given that this latter degree of modal involvement represents a serious issue to Quine, evoking the ambiguous concept of essences, it must be rejected. So the process of extensionalising modalities is performed, with all the modalities and probabilities except for those that are not merely linked to the linguistic form through which they are expressed, but the very nature that a given term designates. In this case, Quine straightforwardly rejects these types of modalities. Quine’s discussion of modality applies to probability too; with probability considered as a *de dicto* modality (i.e., the modal element lies in the linguistic form probability is expressed). For this reason, Quine underlines that probability should be considered in a subjectivist way with probability statements that need to be extensionalised. Furthermore, in this part of the thesis it is argued that probability is a modality that belongs to the third grade of modal involvement. This discussion grounds the one performed subsequently in the thesis regarding probability in QM, which represents a third degree of modal involvement at least in the case of some specific micro-objects that will be taken into account in Chapter III [Ch. I/B]. In the final parts of the first chapter, some incomplete critiques relevant for the theme of this thesis were taken into account, underlining that a deeper and fuller discussion on probability in the Quinean speculation is needed [Ch. I/C].

In Ch. II, Quine's perspectives on probability and some of the several available traditional perspectives on probability in the literature were taken into account in order to compare them with Quine's philosophy and see whether they could be in accordance with Quine's system. In this way, it was considered whether we could find a possible way out for Quine, relying on another compatible perspective on probability. First of all, Quine's preferred subjective probability was explored, and it was clarified that probability for Quine is, in most contexts, understood as subjective degrees of belief and could be rendered in an extensional way using the quotation device, which has been widely taken into account by Quine with *de dicto* modalities. Subsequently, Quine's proposal of extensional propensities to make sense of probability in QM was presented [Ch. II/A]. After that, the thesis focused on a classification of the types of probability, taking into account physical, epistemic and subjective probability, and clarifying that Quine's system seems to cover all of these accounts of probability albeit at different periods of his speculation [Ch. II/B]. In the last part of Chapter II, all the major interpretations of probability were examined, looking closely at Bayesian/subjective probability and objective probability (i.e., frequentism, and the propensity view) and highlighting all the attractive aspects of these viewpoints and their drawbacks. Finally, the chapter highlighted the main difference between propensities, intended in Popper's way, and Aristotle's *potentiae.* This allows the reader to be introduced in an easier way to the discussion performed in the following chapter and clarify the exact nature of propensities [Ch. II/C].

Ch. III of the thesis, was entirely dedicated to QM and the role of probability in the above mentioned field. First of all, Copenhagen, Many Worlds, Cosmological, Hidden Variables, Bohmian Mechanics, Ghirardi-Rimini-Weber (GRW) and minor interpretations of QM were considered with their inherent advantages and deficiencies. This was included so as to have a clearer picture of the current debate on how to interpret QM and its predictions [Ch. III/A]. Afterwards, Heisenberg's account of potentialities was examined, noting that the account draws on Aristotle's *potentia*. The chapter also elucidated Quine's sceptical attitude towards Aristotle's *potentiae.* Given that Quine rejects Aristotelian essentialism, a paragraph is dedicated to the comparison between Aristotelian potentialities and Quine's dispositions looking also at potentialities and extensionalism. Subsequently, the acceptance, through the philosophical community, of Heisenberg's theory of potentialities was taken into account, mentioning Kastner, Kauffman and Epperson (2018) interpretation of quantum potentialities and Suárez (2007) appeal to quantum propensities. After that, it was argued that probability in QM falls in the scope of the third degree of modal involvement, and as such, represents a problematic issue for Quine, with modality appearing to be a property of an object and it is not just linked to the linguistic way in which the modal term is expressed. Therefore, it is seen that modality constitutes the essence of the above mentioned object. This leads to Aristotelian essentialism, according to which objects have accidental and essential properties. These latter ones represent the real essence of the object with a given object that would not be as it is without essential properties. Quine has strenuously fought this view since the idea of essence implies intentionality. It has been noted that the type of probability involved in QM appears to belong to the third grade of modal involvement; thus, difficulties in interpreting it in extensional terms are highlighted [Ch. III/B].

In Ch. IV, I took into account David Lewis' Best System account of laws of nature that is an extensional perspective to establish whether this perspective could implement Quine's viewpoint to make it coherent and in line with QM while preserving naturalism and extensionalism. But, discrepancies between Quine and Lewis' philosophy were appraised, which make it impracticable to include relevant aspects of Lewis' system in the Quinean one. It was argued that Lewis' extensional proposal cannot be accepted by Quine due to a number of points of divergence. Among those, we find the discrepancy between Lewis and Quine's naturalism, the fact that Lewis' is concerned with finding an elegant philosophical account even though it turns out to be in contrast with physics as occurs for Lewis' Humean Supervenience theory, which is not in line with physics, given non-locality, as per Lewis' admission. The chapter firstly focuses on the crucial aspects of Lewis's philosophy, underlining clearly and from the beginning that Quine and Lewis's systems deeply diverge in some aspects, such as Lewis's modal realism and plurality of worlds. After that, Lewis' Principal Principle and his account of laws of nature are considered, underlining the cumbersome points of this perspective. Subsequently, an account of Humean Supervenience was presented, evaluating its basic aspects and the constituents of the Humean base. More on the Humean base is said in relation to the crucial issue of non-locality and Bell's Inequalities, to highlight the way that the assumption of Humean supervenience disagrees with Bell's theorem, and thus, with currently accepted physics. This was regarded as the major problem that prevented us from implementing Lewis' account into the Quinean philosophy and made it unavailable for the above mentioned purpose. On the other hand, it has been considered closeness between Lewis' categorical properties making the Humean base and Quine's molecular structure, although it is highlighted that both the above mentioned perspectives run into problems with the probabilistic elements of QM. More on the divergence between Quine and Lewis is said subsequently, where it is investigated whether Lewis is a Quinean naturalist. It is argued that Quine and Lewis' naturalism widely differ [Ch. IV/A].

Ch. V is dedicated to Quantum Bayesianism (QBism), which is a novel interpretation of QM that aims to solve several peculiar aspects of QM that are usually perceived as ambiguous in the scientific and philosophical community, such as the quantum measurement problem, non-locality and entanglement. One of the cornerstones of QBism is subjective probability and the normative interpretation of the Born Rule. The idea that probability is subjective makes QBism an attractive perspective in terms of a potential inclusion in the Quinean philosophy to preserve its major facets. Ch. V highlights the main features of QBism focusing on the aspects that render QBism an unavailable solution for Quine. First of all, it has been quickly recalled Quine's ontology as a basis for subsequent considerations on the ontology of QBism.

After that, a discussion is performed on the central traits of QBism, such as the treatment of probability, the Born Rule, the evaluation of measurement outcomes and measurement apparatus. Also, the chapter considers the ontology QBism, highlighting how meagre it is. Subsequently, the chapter offers an evaluation of all the advantages that make QBism attractive and the drawbacks attached to this perspective. All in all, a major worry accounted for in the thesis is hinted in this part of the work, i.e., the problem of the explanatory power of the Born Rule interpreted in the normative way [Ch. V/A]. In terms of major theoretical differences between standard QM and QBism it has been highlighted that QBism is not an alternative theory of QM such as, e.g., Bohmian Mechanics that seeks to be an alternative to standard QM relying on a different mathematics. Indeed, QBism is presented by its proponents as an alternative interpretation of standard QM. This means that the mathematics used in QBism is the same used in QM. After that, looking at the scientific and philosophy community the chapter scrutinises how QBism is received, pointing out that QBism remains a minor interpretation of QM that the majority of physicists and philosophers do not endorse. There is no way to determine whether or not QBism could be considered one of our best scientific theories on this basis only, but, this clarifies how QBism is perceived among scholars highlighting that the Copenhagen/standard interpretation remains the favoured one. This highlights that QBism is still not considered preferable to standard QM; thus, it is emphasised that whether Quine's philosophy would benefit from QBism remains in question given his naturalist commitment to base his account of reality on our best scientific theories. Even if Quine could accept QBism despite its being overlooked by the majority of working physicists, there are further issues with the theory that throw doubt on whether it could succeed as a way out for Quine. Amongst these, the chapter addresses the issue of mathematics in the QBist perspective, analysing the aspects of QBist understandings of the mathematics used in QM. In particular, research on how mathematics is perceived by QBists has been conducted and it has been established that Fuchs (one of the major scholar amongst the QBists) advances the idea that even though it cannot be said whether mathematics is subjective at its deepest level, mathematical objects and rules are subjective in QM. The thesis suggests that this could be an important issue in terms of implementing QBism in the Quinean philosophy, given Quine’s commitment to Platonism. The end of the chapter is entirely devoted to the most major problem with QBism, i.e., the fact that the normative interpretation of the Born Rule implies that QBism lacks explanatory power. As said previously, this has been regarded as a major issue with QBism that makes it unavailable to be implemented in the Quinean philosophy given that it is difficult to establish how and why we should conform our beliefs to the Born Rule [Ch. V/B].

In conclusion, the thesis's aim is to shed light on a particular and specific portion of Quine's speculation and QM assumptions, putting them one in front of the other and highlighting that a flaw is appraised in the Quinean perspective. Once considered the above mentioned flaw and took into account its major aspects and facets, this research explores ways to solve it in order to determine whether there is a way to preserve Quine's philosophy as it is. In other words, while it has been established that the fault appraised in the Quinean system is a major one, it has been noted that there was a need to address it. While attempting to address to the contradicting aspect found in the Quinean account, major philosophical perspectives have been taken into account to see whether Quine would have been able to “borrow” some aspects of them and rely, in a way, on those aspects to save his own perspective (i.e. his combination of naturalism and extensionalism) in the light of the probabilistic nature of QM. Of course, it has been established that the other philosophical accounts considered in this work present elements that could be considered attractive from a Quinean perspective, hence the choice of taking into account such above mentioned viewpoints. To perform the discussion on the other philosophical systems considered and compare with Quine's own view, an effort has been made to consider whether the aspects that differ from a Quinean perspective effectively pull apart the above mentioned philosophical systems from Quine's one. It has been noted that the points of discrepancies between the philosophical standpoint included in this thesis and Quine's cornerstones are critical, and thus, key to determining that the above mentioned philosophical perspectives could not benefit Quine's philosophy. Therefore, while this leads to the conclusion that the fault appraised in the Quinean philosophical system is hard to solve, and that the only potential way to address to the flaw previously discussed would be for Quine to drop either extensionalism or naturalism, this opens a range of new lines of research. Thus, our final thoughts in this concluding part of the thesis will be dedicated to the further research that may arise from the arguments pursued in this work, which leaves room for several lines of inquiry.

In this place, two of the potential novel research routes that unravel from the arguments treated in this work will be taken into account. To some extent, the idea that Quine would potentially need to abandon either extensionalism or naturalism is a topic that opens up a number of research possibilities and could lead to interesting results as well. This surely represents an interesting and important new line of research that comes in the wake of the themes treated in this thesis. In addition, one of the arguments of the thesis that will surely need to be enriched in future work is the discussion around QBism and whether QBism and Quine's philosophy could become compatible in the upcoming future. Indeed, the incompatibility between the two above-mentioned strands of reasoning takes into account the current QBist outlook; it cannot be ruled out that some aspects of QBism may change. Highlighting this, turns out to be important. Indeed, QBism itself seems to be an *in fieri* interpretation of QM and looking at the development of QBism in the forthcoming years would mean to continuously improve and enrich the research performed in this work updating it, as well as provide new important occasions for further research.

Without any doubts, and as previously contemplated, other numerous and several paths for novel research could be unfolded from the debate pursued in this thesis, and other scenarios than the ones proposed in the lines above may be investigated, with the ultimate purpose of disentangling fundamental philosophical questions and contribute to the advancement of the state of the art.

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