A BAYESIAN SOLUTION TO THE DUHEM PROBLEM

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ABSTRACT

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In his book *The Aim and Structure of Physical Theory* Pierre Duhem introduces a problem regarding scientific methods which later had been called the Duhem Problem. The Duhem Problem states that when one uses or structures a theory, that theory is not used or structured independently of other theories. Scientific theories are not isolated from each other; we use other theories in the way of constructing or supporting another one. Then, even though a theory is falsified by experiments, we cannot definitely rule out that theory because we do not explicitly know why the theory is falsified. In this thesis, I will examine the viability of Colin Howson and Peter Urbach's Bayesian Probability focused solution to the Duhem Problem. Bayesian Probability explains the relation between evidence and hypothesis with respect to their probabilities. It can show whether the evidence confirms or disconfirms the hypothesis by determining the probabilities of the hypothesis before and after the evidence is considered. According to Duhem, the Duhem Problem is related to his idea that a crucial experiment, meaning an experiment which definitively shows the superiority of one theory over others, is not possible. This means that when a scientist conducts an experiment, it cannot rule

out all possible explanations apart from one because there might always be an explanation of which has not been thought yet. Howson and Urbach claim that individual probabilities of theories can be measured and used to determine where the error lies when theories as a group encounter an error.

Keywords: Pierre Duhem, Bayesian Probability, Howson and Urbach, The Duhem Problem, Bayes' Theorem

ÖZ

DUHEM PROBLEMİNE BAYESCİ BİR ÇÖZÜM

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Pierre Duhem, *The Aim and Structure of Physical Theory* adlı kitabında, daha sonra Duhem Problemi olarak adlandırılan bilimsel yöntemlerle ilgili bir problem ortaya koymaktadır. Duhem Problemi, bir teori kullanıldığında veya oluşturulduğunda, bu teorinin diğer teorilerden bağımsız olarak kullanılmadığını veya oluşturulmadığını belirtir. Bilimsel teoriler birbirinden izole değildir; diğer teorileri, bir başkasını inşa etmek veya desteklemek için kullanırız. O zaman, bir teori deneyler tarafından yanlışlansa bile, o teoriyi kesin bir şekilde dışlayamayız çünkü teorinin neden yanlışlandığını açık olarak bilmiyor oluruz. Bu tezde, Colin Howson ve Peter Urbach'ın Duhem Problemine Bayesci Olasılık odaklı çözümünün uygulanabilirliğini inceleyeceğim. Bayes Olasılığı, kanıt ve hipotez arasındaki ilişkiyi olasılıklarına göre açıklar. Hipotezin kanıtların değerlendirilmesinden önce ve sonraki olasılıklarını belirleyerek kanıtın hipotezi doğrulayıp doğrulamadığını gösterebilir. Duheme göre, Duhem Problemi, yine kendisinin bir teorinin diğerlerine göre üstünlüğünü kesin olarak gösteren bir deney anlamına gelen önemli deneyin mümkün olmadığı fikriyle bağlantılıdır. Bu demektir ki, bir bilim insanı bir deney yaptığında, biri dışında tüm olası açıklamaları dışlayamaz çünkü her zaman henüz üzerinde düşünülmemiş bir

açıklama olabilir. Howson ve Urbach, teorilerin bireysel olasılıklarının ölçülebileceğini ve bir grup olarak teoriler bir hatayla karşılaştığında hatanın nerede olduğunu belirlemek için kullanılabileceğini iddia ediyor.

Anahtar Kelimeler: Pierre Duhem, Bayesci Olasılık, Howson ve Urbach, Duhem Problemi, Bayes Teoremi

To my family

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CHAPTER 1

INTRODUCTION

The aim of this thesis is to investigate whether Colin Howson and Peter Urbach's Bayesian solution to the Duhem Problem is viable or not. I will claim that their solution is a viable one even though they mainly focus on one part of the problem. The part I am referring to is the non-falsifiability part, and the other part of the problem is non-separability, for which I claim the solution also holds.

In the first part of the thesis, I provide some information regarding the historical background of Pierre Duhem's academic career and studies, and then his formulation of and solution to the Duhem Problem. Afterwards, I examine Quine's thoughts that are related to the Duhem Problem, and how Quine's thoughts differ from Duhem's. Then, I focus on Bayesian probability by explaining some axioms and theorems in probability calculus that I believe are important to understand Bayes' theorem. After explaining the related axioms and theorems, I provide information regarding different versions of Bayes' theorem and give some insights into what they mean and how they can be used. Then, I examine the solution proposed by Colin Howson and Peter Urbach to the Duhem Problem, which is a Bayesian solution, and discuss whether it is a viable solution to the Duhem problem or not. I end the thesis by referring to some objections raised against the Bayesian solution and offer some thoughts on how to handle them.

I thought it would be important to take a look at Duhem's life in general, and the opinions dominant in the scientific and academic communities at that time in order to get a better understanding of Duhem's academic career and studies in science and philosophy. For example, Duhem was raised as a religious and a Catholic person, and that played some part in his being interested in science because throughout his education in a Catholic school, Duhem was highly influenced by his science teacher and wanted to study physics. There are negative aspects of his being religious, such as the differences of opinion between Duhem and the French academic community that oppose to the idea of religious figures having a place in academia, and his personal altercations with some powerful figures in the French academic community, and those may as well influence his studies and why he objects to the dominant way of conducting science at the time.

The dominant way of conducting science at the time was the method called the Newtonian Method, or the inductive method. That method states that there are no other truths in physics than experimental facts. This means that theories in science are based upon evidence and data gathered from empirical observations and any imperceivable notion cannot be the basis of a theory. But Duhem argues that we need to use some measurements or instruments that are defined only by theories that we cannot directly perceive with empirical observations. That is why he objects to the rejection of all elements other than observational ones. Duhem's scientific view is sort of a middle way between empiricist and metaphysical views. His view includes both elements that can and cannot be directly perceived by observations. That is why he objects to the inductive method and claims that there are two related problems regarding the inductive method. One of them is the Duhem Problem, and the second is the impossibility of crucial experiments in physics.

We can explain the Duhem Problem by saying that in physics we cannot and do not use theories independently of other theories. We always get help from other theories when we want to use a theory. This might also be called non-separability since theories cannot be used separately from each other. Duhem also states that when we encounter an error, or an observation we do not expect, we cannot determine where exactly the problem lies because of non-separability. We can call this non-falsifiability because we cannot determine which theory is the cause of the error and should be falsified. Therefore, non-falsifiability occurs as a direct result of non-separability.

In the case of crucial experiments, Duhem states that there cannot be any in physics. This is because the concept crucial experiment means that an experiment determinately shows that one of the theories between competing ones is successful and the other is failed. But this is not possible in physics because of non-separability and non-falsifiability. Since we cannot evaluate theories separately, we cannot determinately be certain of the falsifiability of a theory. Also, in order to be a crucial experiment, all possibilities should be evaluated. What I mean is that apart from two competing theories, there might always be a third option that is not yet apparent to the scientists. That is why crucial experiments in physics are not possible.

Duhem gives an answer to these problems. He calls it good sense. When a scientist decides what sort of changes she will make in the system, Duhem says that her guide should be good sense. It is not the choices we make according to logic, but it is a more intuitive type of reasoning. Duhem admits that the decision the scientist makes is not definitively the correct one, but if the scientist satisfies the requirements of the experiment and the error ceases to exist, then the scientist can be satisfied with the result.

Quine's theory regarding the two dogmas is closely linked to Duhem's theory, so much so that later some forms of their theories were combined and called the Duhem-Quine thesis. That is why I believe it is important to examine how Quine's view is different from the Duhem Problem. Quine agrees with Duhem on the thought that we cannot evaluate statements separately from other statements. Quine also says that the boundary conditions of a field of science are experiences, and experiences forming the boundary conditions of the field do not engage with the statements that are in the interior of the field. Only on some occasions that affect the system as a whole, experience might be linked to the interior of the field. However, that does not mean that when an unexpected result happens in the experiment, nothing should be changed. And since the field is not properly determined by the boundary conditions, which is experience, which statements should be re-evaluated is not a clear choice to make. That is why Quine claims that because of the ambiguity of the whereabouts of the cause of error, if we want to confirm a theory, we can do so by making some adjustments elsewhere in the system. According to him, this holds for any theory. And because of the same reason, no theory is immune to revision.

Quine's thoughts differ from Duhem's thoughts with the idea that any theory can be held true if we make the necessary adjustments elsewhere in the system. Duhem does not say anything about the verification of a theory by making some changes. He only states that we cannot know where the error lies. When we say that the Duhem problem consists of two parts, which are non-separability and non-falsifiability, we can say that the Duhem-Quine thesis also includes a statement regarding the confirmation of theories. If we dissect the Duhem-Quine thesis into two parts, they would be: 1) since hypotheses are inseparable, none of them can be falsified in isolation, and 2) if we want to confirm a particular hypothesis, we can do it by making some adjustments elsewhere in the system. As we can see, the second thesis is not in any way related to what Duhem says. Duhem does not say anything about the verification of a theory by making adjustments, he only states that where the error lies cannot be determined.

Providing some information regarding Probability Calculus I believe is necessary to understand the Bayesian solution to the Duhem problem. Some of the concepts might need to be addressed and explained here. Let h be the notation of a hypothesis, and e be the notation of evidence. Prior probability, $P(h)$, means the probability of a hypothesis before evidence. Posterior probability, $P(h / e)$, means the probability of a hypothesis in the light of the evidence. If the posterior probability of a hypothesis is higher than its prior probability, it means that the evidence supports the hypothesis. If the prior probability of a hypothesis is higher than its posterior probability, then it means that the evidence disconfirms the hypothesis. According to Bayes' theorem, the posterior probability of a hypothesis depends on three probabilities, the probability of the evidence conditional on the hypothesis, $P(e / h)$, the prior probability of the evidence, $P(e)$, and the prior probability of the hypothesis, $P(h)$. The theorem states that the posterior probability of h equals to the probability of the evidence conditional on the hypothesis multiplied by the prior probability of h divided by the prior probability of e: $P(h \mid e) = P(e \mid h)\, P(h) / P(e)$, where $P(h)$ and $P(e)$ is greater than 0. This is one version of Bayes' theorem, but some other versions will be introduced and examined later.

Howson and Urbach state that even though theories used as a group are falsified, their individual probabilities are changed. These changes refer to Bayes' theorem and can be explained by Bayesian Probability. Even though Duhem states that we cannot evaluate theories separately from other theories, meaning that there is non-separability, in the light of Bayesian probability, we can say that theories have individual probability values. The probability values of each theory, however, are not measured in isolation from other theories because the theories that are used together or in connection with other theories affect the probability values of those theories. But, again, we can still measure the probability values of individual theories, and this gives us an advantage in the possibility of evaluating theories individually. Afterwards, considering the prior and posterior probabilities of the theories, we can make a decision regarding which theory in the system should be changed or abandoned. The decision we make might not be accurate beyond any doubt, but it would be the highest probable cause of error. I should also note that Howson and Urbach focus more on the falsifiability aspect of the Duhem problem, even though their solution tackles non-separability too.

Throughout their explanation of their Bayesian solution to the Duhem problem, Howson and Urbach use two examples that help to clarify some aspects of the solution. The first of the examples is the ravens paradox. The examples are used to show that hypotheses can be confirmed or disconfirmed to different degrees upon encountering different types of evidence. For instance, if we use the statement in the example, "all ravens are black," seeing something that is non-black non-raven and seeing a black raven both confirm the statement, but the degrees of confirmation they provide are not the same. This example is important because it helps the solution on the way of providing an answer to the non-falsifiability aspect of the Duhem problem since it shows that evidence can confirm and disconfirm a hypothesis and different types of evidence can provide different degrees of confirmation.

The other example, which is about the atomic weight of elements, is used to explain that even though the prior probabilities of statements are reassigned, the result would not change drastically. The example shows that when the prior probabilities of different assumptions are assigned in a way such that they are both more probable to be true than false, if their probability values are different, their posterior probability values happen to be immensely different. In addition, the example also shows that even if the prior probability values of the assumptions are assigned much closer, their posterior probability values would still be significantly different. Therefore, we can say that if the statement's probability of being false is considerably high, even though it is still more probable to be true than false, then the statement is highly likely to be false even after the probabilities are reassigned. The same holds for the scenario of a statement being true.

Showing that even though the assigned prior probability values of hypotheses are changed, the outcome of the calculations would be similar is important because it offers an explanation to one of the criticisms raised against the Bayesian solution to the Duhem problem. The example shows that the assigned priors are not as random or subjective as one might think, and it also shows that the assigned priors do not need to be completely accurate to help us find where the error most probably lies. Hence, while the atomic weight example shows that the assigned priors are not problematic, it also provides insights to an answer to the non-separability aspect of the Duhem problem.

CHAPTER 2

THE DUHEM PROBLEM

This chapter is dedicated to examining the life and works of Duhem in detail. The aim of the examination of his life is to have some idea regarding some of the events that had an impact on him and might have affected his studies and ideas. For instance, Duhem was a religious person and there might be some connections with the troubles he encountered in his academic career and him being religious. There were some obstacles and restrictions he faced in academia. The reason why there might be a connection between Duhem's troubling encounters and him being religious is that at that time the French academic and scientific communities had a highly negative attitude towards religion. But there might be other reasons for Duhem's academic struggles. Another reason might be that some of the theories he defended in his first doctoral thesis resulted in the rejection of some of Marcellin Berthelot's most important studies, who was a powerful figure in the French scientific community at the time. The rejection of his works made Berthelot approach Duhem in a personal perspective, rather than approaching the matter professionally. It seems that Berthelot had a personal grudge against Duhem and blocked some of the offers and opportunities that Duhem might have received. However, apart from the reasons of him being religious and Berthelot's personal grudge against him, some of the troubles he encountered and some of the opportunities he could not get might have been because of him being a highly stubborn person. He might have refused some of the offers he received because of his stubbornness and all of the reasons above might have affected his studies and finally diverted him to the Duhem Problem.

The aim of examining his works is to see in detail how and why he proposes the Duhem problem. What are the reasons that led him to propose the problem? For instance, why does he object to the Newtonian method of conducting science and how is it related to the Duhem problem? In order to answer these questions, I will also examine both the Newtonian method and Duhem's own account of scientific method.

This chapter consists of five sections. In the first section of the chapter, I will provide a historical background for Duhem, his academic career, and some of his research interests. I will also provide some information about the claims regarding the reasons behind his motivation of his works on history and philosophy of science. Then, I will focus on Duhem's views on science and scientific method. After I explain his perspective of science and scientific method, I will emphasize how and in what ways his perspective and the dominant methodology of conducting science at that time are different. In the light of those differences, I will address the reasons why Duhem proposes the Duhem Problem. From the reasons of the emergence of the Duhem Problem, I will draw attention to the importance of non-separability, non-falsifiability, which is a direct result of non-separability, and Duhem's thoughts on crucial experiments.

In the next section, I will specifically focus on his theory known as the Duhem problem. I will show how he formulates his theory and claim that his original formulation focuses on non-separability, not non-falsifiability; however, non-falsifiability is a direct result of non-separability. Afterwards, I will investigate the notion of crucial experiment and Duhem's claim that there are no crucial experiments in physics. I will delve into why Duhem makes such a claim and then, I will show the connection between the Duhem problem and the idea that there are no crucial experiments in physics.

In the third section of this chapter, I will describe Duhem's own solution to the Duhem problem. I will explain how Duhem thinks that good sense can be the solution to the problem and how scientists can act and make decisions in accordance with good sense.

In the final section, apart from the conclusion section, I will examine the relation between the Duhem problem and Quine's additions to it. I will investigate how the so-called Duhem-Quine thesis is formed, and how and in what ways it is different from the Duhem problem.

2.1. Duhem: A Historical Background

Pierre Maurice Marie Duhem was born in Paris on June 10, 1861. His father, Pierre-Joseph Duhem had a Flemish origin who had lived in the northern part of France, close to the Belgian border, while her mother, Marie-Alexandrine Fabre, was from a bourgeois family from the southern part of France, whom they settled in Paris in the seventeenth century. Duhem's father, Pierre-Joseph had studied with the Jesuits; however, after his parents' death, he had to abandon his studies with the Jesuits in order to provide for his family and he had started working as a sales representative in textile industry. Be that as it may, Pierre-Joseph had never lost his love for learning and continued studying whenever he could (Ariew, "Pierre Duhem" sec. 1).

With the influence of Pierre-Joseph's studies with the Jesuits and his never-ending love for studying, and Marie-Alexandrine's bourgeois point of view coming from her family history, Duhem family knew that it is significant to have a quality education; that is why they "made sure that Pierre was well educated" (Ariew, "Pierre Duhem" sec. 1). In addition, they also believed in the importance of religion in one's life. Therefore, Duhem were raised as a Catholic. At the age of seven, Duhem had begun to take private lessons on the subjects of grammar, arithmetic, Latin, and catechism (Ariew, "Pierre Duhem" sec. 1). At the time of the Franco-Prussian War (July 1870 – Feb 1871), the Duhem family left Paris in order to escape from the Prussian forces' advance towards Paris and moved to Bordeaux. They returned to Paris after the armistice in February 1871. Soon after their return to Paris, in March 1871, the Paris Commune seized power of the government with a revolutionary attempt. Even though the Paris Commune's governance only lasted for two months, the effects of their progressive policies, such as "the separation of church from state, the rendering of all church property into public property, and the exclusion of religion from schools," did not vanish with the end of the Paris Commune (Ariew, "Pierre Duhem" sec. 1). Since they were a religious family, the practices and policies inherited from the Paris

Commune did not appeal to the Duhem family, and they rejected and opposed those irreligious acts.

Due to his family's Catholic beliefs and their emphasis put on to having a quality education, Pierre Duhem's education continued at a Catholic school in Paris, starting from 1872 up until 1882. In his book *The Aim and Structure of Physical Theory (1905-6)* Duhem mentions the influence of his science teacher on him:

> Let us take ourselves back twenty-five years to the time when we received our first initiation, as physicist-to-be, in the mathematics classes of the College Stanislas. The man who gave us this initiation, Jules Montier, was an ingenious theorist; his critical sense, ever alert and extremely perspicacious, distinguished with sure accuracy the weak point of many a system which others accepted without dispute; proof of his inquiring mind is not lacking, and physical chemistry owes one of its most important laws to him. It was this teacher who planted in us the seed of our admiration for physical theory and the desire to contribute to its progress. … Being a disciple of Moutier, it was as a convinced partisan of mechanism that we approached the courses in physics pursued at the Ecole Normale. (Duhem, *The Aim and Structure* 275–276)

It can clearly be seen in Duhem's own words that his science teacher in College Stanislas, Jules Montier, greatly influenced and encouraged his students who want to pursue a study in science. Pierre Duhem was one of them.

Duhem became a student in *Ecole Normale Supérieure*, which is a higher education institution in 1882. Unlike his previous school, which was a Catholic school, *Ecole Normale Supérieure* was a secular institution. Amongst a highly successful group of students, Duhem entered the school as the first in the Science Section, and he remained as the first throughout his education there (Ariew, "Pierre Duhem" sec. 1). At the end of the 1883-1884 academic year he received diplomas in both mathematics and physics. Even though the standard period of education in *Ecole Normale Supérieure* was three years, Duhem was granted permission for a fourth year, then he continued his studies for a fifth year with the title of *agrégé préparateur*[1] (Ariew, "Pierre Duhem" sec. 1).

[1] Translated as assistant preparer.

In his third year in *Ecole Normale Supérieure* in the academic year 1884-1885, Duhem's thesis on the subject of thermodynamic potential for his doctorate in physics was rejected by a jury consisting of physicist Gabriel Lippmann, and mathematicians Charles Hermite and Emile Picard. Duhem's thesis was rejected by the jury, and it is claimed that the rejection decision was a political one (Ariew, "Pierre Duhem" sec. 1).

One of the reasons why Duhem's thesis got rejected might be because of the social, cultural, and intellectual context of the French scientific community. At the time of the end of the nineteenth century, scientists in the French scientific community were strictly opposed to the idea of religious establishments and the members of those religious establishments taking part of administrative or governmental decision-making processes, while Pierre Duhem was an openly conservative and religious person; he was also most of the time stubborn and combative. However, since Duhem presented and defended another thesis in 1888, this time for a doctorate in applied mathematics, and his dissertation was accepted by a jury consisting of physicist Edmond Bouty, mathematician Gaston Darboux, and mathematician-physician Henri Poincaré (Ariew, "Pierre Duhem" sec. 1), the claim about the social, cultural, and intellectual context of the French scientific community might be considered a weak one.

A stronger claim regarding why Duhem's first thesis got rejected might be based upon the relationship between the head of his first dissertation jury, Gabriel Lippmann, and Lippmann's close friend, and also a powerful figure in French scientific community, Marcellin Berthelot. Duhem's thesis on thermodynamic potential refuted a theory regarding maximum work upon which one of Berthelot's most revered theories was based. This might be a compelling argument why Duhem's thesis was rejected. Berthelot was a highly influential figure and when he said, "This young man will never teach in Paris," (Paul 211), referring to Duhem, it can be seen that Berthelot took the matter personal and apparently was quite angry at Duhem. And, Berthelot's claim, or maybe a promise, came true; Duhem had never taught in Paris for the remainder of his life.

Duhem spent the rest of his academic career outside of Paris. He worked and taught in Lille, Rennes, and Bordeaux, but could not return to Paris. At the later stages of his life, he was offered a position in the department of History of Science in *Collège de France*; but he refused to be a candidate for the position. Even though Duhem explained his reason that he refused the offer to his daughter by saying, "I am a theoretical physicist. Either I will teach theoretical physics at Paris or else I will not go there," (Wisniak 158) one can say that his pride and stubbornness also played a role in his decision.

Armand Lowinger in his book *The Methodology of Pierre Duhem* in 1941 addresses a claim regarding the importance of energetics to Duhem and Duhem's works on history and philosophy of science that all of Duhem's works on history and philosophy of science were done in order to defend his works and methods in energetics (Ariew, "Pierre Duhem" sec. 1).[2] Furthermore, in R. Niall D. Martin's book *Pierre Duhem: Philosophy and History in the Work of a Believing Physicist* in 1991, and in Stanley Jaki's book *Scientist and Catholic: an Essay on Pierre Duhem* in 1991, the importance of religious motivations behind Duhem's works is addressed (Martin 15–28; Jaki 53–57). It is said that Duhem's expectation was the idea that science would eventually be in a form such that it will become coherent, or compatible, with the teachings of the Catholic Church. Regardless, it might be unjust or unfair to claim that all of Duhem's work on the subjects of history and philosophy of science were because of the defense of the methods and historical position of energetics, or only because of a religious motivation. It might also be an incomplete or a misinterpreted reading of his works. He might have started with such motivations, but his works encompass much more than those motivations, and have been elevated to another level.

[2] For more information, see Armand Lowinger's 1941 book *The Methodology of Pierre Duhem*.

2.1.1. Duhem's Perspective on Science and Scientific Method

In terms of his views regarding science and scientific knowledge, Duhem is not a person whom one can confidently say that he is, for instance, on the side of metaphysical conception of science, or on the side of pragmatist conception of science. Or, two sides may be thought as, say, foundationalist, and relativist conceptions of science. José Raymundo Novaes Chiappin in the abstract of his article "A Methodology for the Theory of Science and its Application to the Reconstruction of the Metaphysical Level of Duhem's Theory of Science" says that Duhem constructs a theory of science such that it is a conception of structural and convergent realism, and states that this conception is sort of a "middle way" between the metaphysical and conventionalist, or pragmatist, conceptions of science (Chiappin 19). Chiappin defines Duhem's theory of science as being a dynamical theory of knowledge. This is because, according to Chiappin, the aim of Duhem's theory of science is to demarcate his interpretation of theoretical physics in the aspects of a foundationalist interpretation of physical theory, and a relativist interpretation of physical theory on two sides (Chiappin 19–20). Therefore, Duhem's theory of science cannot be considered solely as being a conventionalist conception of science.

Chiappin distinguishes three stages of Duhem's methodology of theory of science, which are metaphysical, logic of science, and history of science. These three stages consist of three types of propositions: ontological theses, epistemological theses, and axiological theses. The aim of Chiappin's "formulation" of Duhem's methodology is to "reconstruct" Duhem's metaphysical stage of theory of science (Chiappin 19).

In the metaphysical stage, the general ideas of Duhem's perception of theoretical physics are defined. In order to define those general ideas, ontological theses are used to describe Duhem's view regarding the nature of the real world. In addition, ontological theses are also used as a regulative principle to be able to describe the transcendental nature of an ideal physical theory. At this point, Chiappin argues that Duhem supports a thesis of structural realism as the nature of theoretical physics

(Chiappin 20). With the epistemological theses, Chiappin assumes that Duhem supports a notion of convergence of truth, that leans towards a more pragmatic view. Nevertheless, according to the notion of convergence of truth that Duhem supports, physical theory yields knowledge regarding the external world within a dynamical point of view. In this way, Duhem's notion of convergence of truth resembles more to a natural classification of the physical laws, rather than, say, a constructed classification (Chiappin 20). The last type of propositions, the axiological theses, define, or state, the aims, and goals of what one's interpretation of theoretical physics hopes to achieve. Furthermore, the axiological theses determine the values and virtues that a strong and reliable physical theory needs to possess in order to be able to reach its aims and goals. One of those aims, for instance, is that theoretical physics cannot be *indeterminate* or *contradictory*. These sorts of values are necessary in order for Duhem's understanding of theoretical physics to be a rational understanding of theoretical physics. His understanding of theoretical physics, for Chiappin, needs to be able to support a kind of value of knowledge with regards to physical theory, and corroborate the constant and progressive advancements and developments of that kind of value of knowledge towards an ideal physical theory (Chiappin 20).

The second stage of Duhem's theory of science, which is the logic of science, can be considered as the group of principles that are used in the construction of his theory of science. The main interest of Duhem's methodology is to be able to grant a rational account of choice of physical theories. In this sense, Duhem's methodology consists of two methods, namely critical and abstract methods. Critical method is used for the evaluation of the relation between theory and experience. In addition, it is also used for deciding which theory should be chosen amongst multiple competing physical theories. Abstract method, on the other hand, is used for composing physical theory. For this reason, the function of the abstract method for physical theory is to operate within the theory to define the components of the theory (Chiappin 21).

The third and final stage of Duhem's theory of science, the history of science, is composed of his understanding of nature, and the role of history in his conception of scientific theory. At this stage, Duhem seeks arguments that can be beneficial for his conventional interpretation of theoretical physics to acquire its validity. Duhem conceives the nature of history as being an empirical science. That is why, while he seeks to find arguments that can assist the defense of his metaphysical and methodological theses, Duhem attributes a methodological function to the nature of history. Since the main interest of Duhem is the rationality of scientific growth, or progress, the usage of a historical element puts an emphasis to the significance of the problem of the growth, or the progress, of scientific knowledge (Chiappin 22).

The purpose of the "reconstruction" of Duhem's theory of science, as Chiappin calls it, is to show that Duhem's theory of science offers an epistemological account of a unified physical theory of science between foundationalist, or metaphysical and empiricist or inductivist, and relativist, or conventionalist or pragmatist, accounts of physical theory of sciences. In addition to that, it is argued that at the base of his understanding of scientific progress and growth, there is a convergent theory of truth. Also, his understanding of scientific progress and growth depicts a dynamic theory of scientific advancement. Therefore, the growth of scientific knowledge, for Duhem, is rational and continuous (Chiappin 23–24).

2.1.2. Duhem's Reasoning for Proposing the Duhem Problem

When we take a look at Duhem's perception of science and scientific knowledge, we can say that Duhem had problems regarding the dominant scientific method accepted by scientists, *the Newtonian Method* (Duhem, *The Aim and Structure* xxii).[3] Let us examine why Duhem does not agree with the Newtonian method of conducting science and how he ends up with proposing the famous *Duhem Problem*.

[3] The preface of Duhem's *The Aim and Structure of Physical Theory* written by Jules Vuillemin provides additional insights regarding Duhem's interpretation of the Newtonian method of conducting science and how Duhem disagrees with it. For instance, in the page xxii, Vuillemin states that Duhem shows that Newton's theories regarding gravity and mechanics were not reached through induction from Kepler's empirical laws; however, Duhem also assumes that Kepler reaches his laws through induction.

The Newtonian method is also referred to as the inductive method. In this scientific method, “basic observational propositions are truths; sensible intuition is the faculty of knowledge; and the criteria of truth is clarity and distinction. There are no other truths in physics than experimental facts” (Chiappin 26). This means that the theories that are accepted or admitted are the ones that are built upon the hypotheses supported by the data provided from empirical observations. Any imperceivable, imperceptible notions, entities cannot be the basis of a theory, or be used to justify a theory. The justification of a theory, in the case of the Newtonian method, acquired through evidence and data gathered from empirical observations, and by using the inductive method. The rejection of metaphysical notions and the acceptance of only the observational notions, or entities, is the view of the Newtonian method which Duhem finds problematic. I mentioned before that Duhem’s theory of science also contains empirical elements, meaning that empiricism is not what Duhem rejects. However, I also mentioned that Duhem’s theory of science also contains metaphysical elements. What Duhem does not find acceptable is that the Newtonian method, or the inductivist method, rejects all elements other than observational ones. That is why, Duhem considers the Newtonian method as not being a manageable way of conducting science, at least not for physics (Duhem, *Essays* 234). The reason why Duhem thinks the Newtonian method is not a manageable way of conducting science is that we may not be able to observe, or at least directly observe, everything that we need and want to observe; and as a result, we need to, and indeed do, use some instruments. Some of those instruments are the terms, elements, and measures of magnitudes that are defined only by mathematical theories. But those are not notions, or entities, that we can directly perceive with empirical observations. At this point, Duhem states that the application of the inductive method becomes troublesome and says, “[w]hen science no longer observes facts directly but substitutes for them measurements, given by instruments, of magnitudes that mathematical theory alone defines, induction can no longer be practiced in the manner that the Newtonian method requires” (Duhem, *Essays* 234). In other words, the functionality, and the applicability of induction as a scientific method becomes not only problematic for Duhem, but also unacceptable.

Duhem states that the Newtonian method might be used for some sciences. They might produce principles and build theories with those principles according to the data gathered from observations by using induction, and also refute theories according to the results of those observations and experiments. However, he says that the Newtonian method cannot be used for all sciences, including physics. For instance, Duhem states that the Newtonian method does not hold for his theory of energetics:

> One can conceive of theoretical physics in the Newtonian manner. One rejects any hypotheses on the imperceptible bodies and on the hidden motions which could compose the bodies and movements attainable through the senses and by the instruments. The only principles that are accepted are the very general laws known by induction from the factual observations. Our energetic does not follow the Newtonian method. (Duhem, Essays 232–233)

In addition, as he states in his writings too, Duhem's focus is physics; and he states that his theories and examinations are within the framework of physics.[4] And, he says that the inductive method is not an applicable method for physical sciences. The reason why he thinks that the inductive method does not work for physics is twofold: the first one is the theory which later were called *the Duhem Problem*: in physics, when a scientist produces a theory, she cannot produce or use that theory independently, or separately, from the hypotheses and theories that form, or are used to form, the theory (Duhem, *The Aim and Structure* 182). Some scholars, Roger Ariew in particular, also calls the Duhem problem the non-separability, or separability, problem (Ariew, "The Duhem Thesis" 318). This non-separability, or non-independence, also causes a sort of non-falsifiability, because when one cannot evaluate theories separately, or individually, she also cannot evaluate their falsifiability. Therefore, she cannot know which theories are falsified and which are not. The second reason why Duhem thinks that the inductive method does not hold for physical sciences is his views regarding crucial experiments in physics. According to Duhem, crucial experiments are not possible in physics (Duhem, *The Aim and Structure* 188). This is because, also having

[4] This can be seen in Duhem's *The Aim and Structure of Physical Theory*:

> We shall in this book offer a simple logical analysis of the method by which physical science makes progress. Perhaps certain readers will wish to extend the reflections put forth here to sciences other than physics … but … we have scrupulously avoided both sorts of generalization. (3)

a relation with the Duhem problem, in order for an experiment to be considered as a crucial experiment, it needs to show without any doubt that one of the competing theories is successful and the other has failed. However, it is not possible in physics that an experiment can determinately show which theory is the prevailed one amongst different competing theories because (1) there should not be anything similar to non-separability so that the falsifiability of the theories can clearly be determined, and (2) the scientist needs to be able to examine all possibilities, which is not possible (Duhem, *The Aim and Structure* 190).

Now, in the next section, let us examine in more detail Duhem's claims regarding non-separability and crucial experiments in physics, and how he produces the Duhem problem.

2.2. Duhem's Formulation of the Problem

In the light of Duhem's thoughts regarding the Newtonian method of conducting science, and the method of induction, he states that experimental data gets to have a more significant role than it should when it comes to assessing and evaluating theories. The effects of over importance given to the experimental data can also be seen in the produced theories. Duhem claims that facts and the theories one produces with the help of experiments in physics become inseparable from each other, or facts cannot be expressed independently from theories by saying, "[t]he analysis we have given of experiments in physics shows fact to be completely interpenetrated by theoretical interpretation, to the point where it becomes impossible to express fact in isolation from theory, in such experiments" (Duhem, *Essays* 237). Here one can see how Duhem's proposed concerns over non-independence is formed. Duhem sees that the over importance given to experiments in the Newtonian method leads to the emergence of the non-separability, or non-independence, problem.

Another perspective, emphasized by Duhem, of the over importance given to experiments in the Newtonian method is that the experiments in physics are treated such that they are crucial experiments. Crucial experiment means that an experiment that can conclusively and decisively determine which theory is disconfirmed, and which is confirmed amongst competing theories. However, Duhem states that there are no crucial experiments in physics. This is because in order for an experiment to decisively determine whether a theory is confirmed or disconfirmed, it needs to take all possible explanations into consideration. But this is not possible. When an experiment is conducted, there will always be an outcome that has not yet been considered. This means that when a scientist conducts an experiment, it cannot rule out all possible explanations apart from one because there might always be an explanation of which has not been thought yet. Furthermore, an experiment also cannot definitively show that amongst two competing theories, one is superior to the other because an experiment can be conducted that shows the opposite; or, there might always be a third unrevealed option.

In order to show why the widely accepted method of conducting science, namely the Newtonian method or the inductive method, should not be accepted, Duhem forms the Duhem problem, and the idea that there are no crucial experiments in physics.

2.2.1. The Duhem Problem

In his book *The Aim and Structure of Physical Theory (1905-6)* Pierre Duhem introduces a problem regarding scientific methods which later had been called the Duhem Problem. He states that when one uses or structures a theory, that theory is not used or structured independently of other theories (Duhem, *The Aim and Structure* 183). Scientific theories are not isolated from each other; we use other theories in the way of constructing or supporting another one. Then, even though a theory is falsified by experiments, we cannot definitely rule out that theory because we do not explicitly know why the theory is falsified. In addition, when one receives a disconfirming result while she is testing the theory, the initial reaction of the scientist can be not to discredit the entire theory but to focus on auxiliary theories because "the option is always open to reject auxiliary theories rather than the hypothesis itself" (Bovens and Hartmann 6). This is because one of the auxiliary theories might be the cause of the problem and rejecting an auxiliary theory might be the more convenient, or logical even, option for the scientist rather than abandoning the whole hypothesis when she is not certain that the whole hypothesis does not work. Then, how can we decide which theory is more tenable when there are two or more theories even if they both receive disconfirming observational data? The observational data, as we have discussed above, may not cause the rejection of the whole hypothesis, and cannot determinately give insights regarding which theory is more tenable since experiments do not possess that kind of power in physics (a topic which we will discuss more broadly). Or, when an error occurs in the process of constructing or testing a theory, how can we decide which part of the theory should be changed or which part of the theory is the reason of the error?

It is true that the focus of the problem seems to be falsifiability, or rather non-falsifiability but what Duhem's main objection towards the Newtonian method, and what the Duhem problem, focuses on is non-separability, or non-independence. Non-falsifiability occurs as a direct result of non-separability. Duhem does not directly emphasize non-falsifiability, or does not structure his theory around it. What Duhem states is that the theories we use in physics cannot be isolated from the theories and hypotheses utilized to build those theories. And this failure to isolate theories from each other brings forth non-independence or non-separability because we fail to evaluate theories individually. That is why there emerges the problem of non-falsifiability because even though one confronts a disconfirming evidence, she cannot be certain that the evidence falsifies the whole theory, or one of the auxiliary theories, or a part of the theory. As Duhem says, the only thing of which she can be certain is that there is an error, "but where the error lies is just what the experiment does not tell us" (Duhem, *The Aim and Structure* 185). Thus, experiments in physics do not provide us the information required to eliminate one theory and choose the other.

Non-separability is the reason that it is not certain which theory should be abandoned if an experiment bears unexpected results, or whether it is possible to reject one of the auxiliary theories rather than the whole theory or not. Moreover, because of non-separability, a similar but kind of reverse situation might also happen, “if the predicted phenomenon is not produced, not only is the questioned proposition put into doubt, but also the whole theoretical scaffolding used by the physicist” (Duhem, *The Aim and Structure* 185). In other words, if the reason for the occurrence of an error is one of the auxiliary theories but due to the non-separability problem, the scientist does not know where the error lies, the situation puts whole theory at risk of being rejected or abandoned.

Now, we can deduce that the Duhem problem, when the focus is on non-separability, entails that for every theory *T*, and observational consequence *e* in physics, no *T* by itself can have *e*, since, “[t]he physicist who carries out an experiment, or gives a report of one, implicitly recognizes the accuracy of a whole group of theories” (Duhem, *The Aim and Structure* 183). Similarly, we can deduce regarding non-falsifiability that no *T* can determinately falsified by *e* alone.

More elaborately, let *T* be the theory we want to test and let *e* be the expected result, or the observational consequence, after testing. If we encounter a result that is not expected, let us call it ~*e*, then our theory is falsified, meaning that we get ~*T*. We can show that by using the *modus tollens*[5] rule:

T→e

~e

∴ ~T.

However, the inference we make here only holds when we can evaluate theories separately from other theories, and according to Duhem, this is not the case. Since we can evaluate theories as a group, we need to replace *T* with a group of theories. Let T_1 be one of the theories in the group, and T_2 be another, ..., and let the last of the theories

[5] The rule states that P→Q, ~Q ∴ ~P. This means that if we have the negation of the consequent of the conditional claim, then we can conclude that we also get the negation of the antecedent of the conditional claim.

we use be T_n. Then, the group of theories becomes $(T_1+T_2+\ldots+T_n)$. Hence, our equation turns into:

$(T_1+T_2+\ldots+T_n)\rightarrow e$

$\sim e$

$\therefore \sim(T_1+T_2+\ldots+T_n)$.

The equation shows us that, according to the theory Duhem proposed, if we encounter an unexpected result after testing, we cannot know for certain that which theory we used is the cause of the unexpected result; one thing we know for certain is that there occurred an unexpected result.

2.2.2. Crucial Experiment

In the light of the Duhem problem, Duhem also mentions that an experiment called a crucial experiment is not possible with regards to the theories in physics (Duhem, *The Aim and Structure* 188). Crucial experiment was thought to be one that showed an experiment which definitively shows the superiority of one theory over others. In other words, a crucial experiment could help one determine which theory should be chosen, or which theory, or theories, does not hold. Be that as it may, Duhem states that physics cannot bear any crucial experiments. This is because, according to Duhem, a contradiction reached by an experiment in physics does not have the power to make a hypothesis indisputably true or indisputably false (Duhem, *The Aim and Structure* 190).

It should be noted here that Duhem does not claim that all experiments are considered as such. He mentions two types of experiments, namely *experiments of application,* and *experiments of testing* (Duhem, *The Aim and Structure* 183). The first type of experiments, the experiments of application, are not conducted in order to determine whether a theory is true or false (Duhem, *The Aim and Structure* 184). They only aim to make use of a theory. They aid science to increase its practicality; however, they cannot be used for creating and developing new scientific theories. The experiments of testing, on the other hand, are the kind of experiments that are conducted for creating and developing theories (Duhem, *The Aim and Structure* 184). They are also the experiments used to reject or dispute theories. When a scientist has a doubt regarding a certain theory, in order to demonstrate the falsity of the theory, she gets help from a prediction regarding an experiment. She conducts the experiment with the hope that her prediction is to be produced. Then, the fate of the disputed theory is determined based on the occurrence of the said prediction. If an experimental contradiction occurs, the disputed theory is falsified.

In order for an experimental contradiction to acquire that power, firstly, the theories we use need to be rid of the non-separability problem since no theory in physics is used, and can be used, independently of other theories. When a scientist intends to show the falsity of a theory and make use of a prediction derived from the theory, she does not use only the disputed theory, but she "makes use also of a whole group of theories accepted by [her] as beyond dispute" (Duhem, *The Aim and Structure* 185). This means that the prediction intended to be used for the demonstration of falsification of the theory does not derive solely from the disputed theory, but rather it is derived from a group of theories. Therefore, whether the prediction occurs so that the disputed theory can be falsified or not does not have the conclusive power to determine the fate of a theory regardless of the outcome of the experiment.

Lastly, in order for an experimental contradiction to acquire the power of determining a hypothesis being indisputably true or false, one needs to examine all possibilities, "but the physicist is never sure he has exhausted all the imaginable assumptions" (Duhem, *The Aim and Structure* 190). Duhem exemplifies his claim with an experiment regarding two theories concerning the nature of light with respect to two systems of optics; on the one side Newton's system of optics stating that light consists of particles, and on the other side Huygens' system of optics stating that light consists of waves (Duhem, *The Aim and Structure* 189). The experiment is conducted in a way that in the end it can be decided definitively whether light consists of particles or waves. Even though the experiment shows that light consists of waves, Duhem states that the experiment is only between two competing theories: “Light may be a swarm of projectiles, or it may be a vibratory motion whose waves are propagated in a medium; is it forbidden to be anything else at all?” (Duhem, *The Aim and Structure* 190). In other words, the possibility of light consisting of something different from both particles and waves cannot go unnoticed. Furthermore, another thing that should be noticed is whether the experiment is in fact a crucial experiment or not. It may not be the case that the experiment is crucial because one might conduct another experiment for two competing theories of light in a way that it shows that light consists of particles. Or, there might occur an experiment which shows that light is neither; there might be a third possibility: “Shall we ever dare to assert that no other hypothesis is imaginable?” (Duhem, *The Aim and Structure* 190). Therefore, it is not possible to conduct a crucial experiment in physics.

Then, how can a scientist ever be sure of any of her findings and the viability of her proposed theories? How is it possible for her to continue her studies when she encounters an error she cannot investigate thoroughly exactly where the error lies?

2.3. Duhem’s Solution: Good Sense

Duhem’s answer to these problems is good sense. He states that the scientist, when she is faced with an experiment which contradicts the results of the theory, either she acts more conservatively and tries to protect the fundamental hypotheses of the theory “by complicating the schematism in which these hypotheses are applied, by invoking various causes of error, and by multiplying corrections,” or she acts in a way to change some fundamental hypotheses which supports the whole theory (Duhem, *The Aim and*

Structure 217). How can the scientist do that? Good sense should be her guidance. Duhem explains what he calls good sense by saying:

> Pure logic is not the only rule for our judgments; certain opinions which do not fall under the hammer of the principle of contradiction are in any case perfectly unreasonable. These motives which do not proceed from logic and yet direct our choices, these "reasons which reason does not know" and which speak to the ample "mind of finesse" but not to the "geometric mind," constitute what is appropriately called good sense. (Duhem, *The Aim and Structure* 217)

In other words, the choices we make not according to logic, but rather according to more intuitive reasoning with our "mind of finesse," are the ones directed by good sense. Good sense can help us determine which theories or hypotheses should be abandoned and where the error lies. Even though Duhem admits that we cannot know for certain which part is the cause or which part should be taken out, that we can only know for certain that an error has occurred, if the two types of scientists manage to satisfy the requirements of the experiment, then they can be satisfied with what they accomplished (Duhem, *The Aim and Structure* 217). Therefore, there is no definitive or absolute way of determining which theories should be refuted, or which theories are at fault when an error occurs; however, with good sense, the scientist can make the necessary adjustments required to eliminate the error.

The two types of scientists mentioned above are, according to Duhem, a timid scientist and a bold scientist (Duhem, *The Aim and Structure* 216–217). The timid scientist approaches an error with more caution and acts to protect certain parts of the theory that are essential to the theory. She makes changes to the auxiliary theories and tries to preserve the main structure of the theory. This approach is indeed a more cautious one, while it is also more complicated since it requires delicate work to protect the core structure of the theory. The bold scientist, on the other hand, proceeds with a more direct approach and may decide to change a fundamental part of the theory. This approach might be less complicated, but it might also be riskier. However, a scientist cannot and should not judge another scientist because of the path she chooses since the reasons of good sense are not absolute, "[t]here is something vague and uncertain about them; they do not reveal themselves at the same time with the same degree of clarity to all minds" (Duhem, *The Aim and Structure* 217). One might choose to handle the situation with more caution, while another might choose to act more directly. As long as they succeed at eliminating the error, we can say that they act in accordance with good sense.

2.4. Duhem-Quine Thesis

There is a significant connection between the thoughts of Duhem and Quine. This connection has another feature regarding Duhem's works. Quine's article "Two Dogmas of Empiricism" published in 1951 had made Duhem's claims regarding the non-separability and non-falsifiability of hypotheses resurface and more widely known. Before Quine's article was published, Duhem's claims had not attracted a lot of attention and were not widely known. But after Quine's article, Duhem's theories and specifically the Duhem Problem started getting a significant amount of attention (Szałek 73). Furthermore, not only Duhem's original formulation of the Duhem Problem, but also Quine's interpretation of the problem, mainly being called the Duhem-Quine thesis or problem afterwards, became widely known. Both versions of the problem had been investigated and examined many times with perspectives such that what kind of differences the two sets of claims possess, what Quine adds into his own interpretation that the Duhem's version does not contain, what kind of differences these additions bring. Here, I will examine Quine's formulation of the problem and its differences from Duhem's original version.

According to Quine, there are two dogmas by which modern empiricism is conditioned. The first of the dogmas is "a belief in some fundamental cleavage between truths which are analytic, or grounded in meanings independently of matters of fact, and truths which are synthetic, or grounded in fact" (Quine 20). This means that there is a belief amongst empiricists that there is a clear distinction between analytic and synthetic truths. Quine here defines analytic truths as meanings that are grounded independently of matters of fact, while he defines synthetic truths as being grounded on matters of fact. In other words, analytic truths are the truths that require no data from sense-experience in order to be considered true, while synthetic truths require data from sense-experience for determining their truth values.

The second dogma is “reductionism: the belief that each meaningful statement is equivalent to some logical construct upon terms which refer to immediate experience” (Quine 20). Quine’s second dogma states that there is another belief amongst empiricists that every statement has an equal statement constructed by using logical properties. This means that every statement can be transformed or translated into a logical structure.

The second dogma, with its reference to a language of immediate experience, resembles Rudolf Carnap’s ideas regarding reducing all statements to a language of immediate experience (Carnap, *The Logical Structure* 154). However, in his later works, in his book *The Unity of Science* for instance, Carnap states that the language which all statements are reduced to does not have to be a language of immediate experience. He says that it does not matter what kind of language that all statements are translated into, as long as they are all translated into the same language (Carnap, *The Philosophy of Rudolf Carnap* 51). The reason why Carnap thinks that all statements are reducible to one common language is his idea that science “is a unity, that all empirical statements can be expressed in a single language, all states of affairs are of one kind and are known by the same method” (Carnap, *The Unity of Science* 32). In other words, science does not consist of separate fields of studies, it is a unity, and all empirical statements are identified by the same methods of conducting science.

Quine states that both of those dogmas are thoughts that are baseless or thoughts that have no solid ground. For him, abandoning the two dogmas results in two effects. One of the effects is “a blurring of the supposed boundary between speculative metaphysics and natural science” (Quine 20). As we shall soon see that this effect refers to the first dogma, and Quine means analytic statements when he says speculative metaphysics, while he means synthetic statements when he says natural science. He states that when we get rid of the dogma, we can see that the boundary between the two statements is not as clear and distinct as we once thought; it is rather blurred. The second effect of abandoning the two dogmas is a change in the direction of pragmatism (Quine 20).

2.4.1. Quine's Interpretation of the Problem

Quine defines a notion of radical reductionism when he talks about the second dogma, the dogma of reductionism, by saying: "every meaningful statement is held to be translatable into a statement (true or false) about immediate experience" (Quine 36). According to radical reductionism, every statement that has a meaning has an experiential counterpart. In that case, there emerges a thought that every statement, when taken in isolation from other statements, can possess confirmation or disconfirmation. Quine claims that the thought of each statement taken in isolation being able to have confirmation or disconfirmation is the assumption that makes the survival of the dogma of reductionism possible. Quine does not agree with the possibility of evaluating statements in isolation, he states that statements can be evaluated only as a group, not individually. He proposes a view regarding that our statements "about the external world face the tribunal of sense experience not individually but only as a corporate body" (Quine 38). On the contrary to the claims of reductionism, we cannot evaluate statements separately from other statements. Consequently, Quine rejects the reductionism's claim that each statement has a counterpart in the external world with regards to the topic of individuality of statements, and defends the idea that statements have a connection with the external world as a group. This idea of Quine brings us closer to Duhem's views.

Quine states that the dogma of reductionism and the dogma stating that there is a clear distinction between analytic and synthetic statements are closely connected. They are essentially identical even. When explaining how they are identical, he says that a limiting statement, which is an analytic statement, also needs to be mentioned because there exists such a statement when we talk about the confirmation or disconfirmation of a statement (Quine 38). The limiting statement is confirmed *ipso facto*, meaning that it is confirmed based upon already known facts. The reason why there exists a limiting statement confirmed *ipso facto* is the view that for both dogmas when confirmation or disconfirmation is concerned, a statement can be analyzed in a way such that it can be separated into its linguistic and factual components. Factual components mentioned are confirmatory empirical data, meaning that they are experiences that have the capability to confirm or falsify a statement. As for linguistic components, they are the elements of the language that is being used. When we reduce statements to the factual and linguistic components, a statement would be analytic on the instances where the linguistic components alone matter, while a statement is synthetic on the instances where both of the components matter. In this way, we can see that the two dogmas are essentially identical.

Quine thinks differently about the linguistic and factual components. He states that it is meaningless to speak of linguistic and factual components where an individual statement's truth is concerned. There is a dependence of language and experience in science when statements are taken collectively, but this dependence is not noticeable when the statements used and constructed in science are taken individually (Quine 39). In other words, when we deal with statements independently from other statements, we cannot acquire the important things regarding scientific statements that we acquire when we deal with them collectively. Quine's view regarding scientific statements that we handle them collectively is a similar view to Duhem's non-separability view. Both Duhem and Quine are saying that scientific statements cannot be evaluated and handled individually, they need to be evaluated and handled as a group.

All of what we call knowledge, all of the subjects and fields that we call knowledge, whether it is geography, or history, or physics, or even pure mathematics and logic, are all human constructs that make use of experience only as a small piece. Or more accurately, rather than making use of it only as a small piece, experience is in interaction with all of what we call knowledge in the process of determining and drawing its boundaries: "total science is like a field of force whose boundary conditions are experience" (Quine 39). This means, in a way, that experience is not linked to the core parts of theories, experience does not have a connection with the fundamental parts of theories. Quine states something similar, only some special circumstances experience can be indirectly linked with the core parts of theories, but these circumstances must be ones that affect the system of theories as a whole. Other than the special circumstances affecting the system as a whole, “no particular experiences are linked with any particular statements in the interior of the field” (Quine 40). Thus, this is again another statement that resembles Duhem’s non-separability view since experience only interacts with the core part of theories when there is concern for the whole system.

Be that as it may, even though experience has no connection with the core part of theories, a conflict with experience may cause the need to change or adjust some of the core parts. Some statements might need to be changed, and the change of re-evaluation of them might cause some other statements to also be changed or re-evaluated. This is because the statements cannot be evaluated or used separately from other statements; they are linked to one another. Furthermore, even though the boundaries of the system are determined by experience, the boundary conditions are not sufficiently determined. And it is not clearly apparent that which statements should be changed or which ones should be re-evaluated because of the connection between statements and that the boundary conditions of the system is not sufficiently determined: “the total field is so undetermined by its boundary conditions, experience, that there is much latitude of choice as to what statements to re-evaluate in the light of any single contrary experience” (Quine 39–40). Therefore, when the scientist is faced with a contrary experience, the choice of which statements to change and as a result of which changes the contrary experience would cease to be a problem anymore are not apparently clear decisions to make.

Quine focuses on the notion of verification with regards to the problem of statements being evaluated individually, and the situation of experience not being able to affect statements individually. He states, similar to what Duhem states, that since statements are not linked to experience one by one, rather they are linked to experience as a group, when there is an error occurred, it is not an easy task to establish where in the group of statements exactly is the cause of error and to fix the error. However, because of the ambiguity of whereabouts of the cause of error, if we want to confirm the theory, we can do so by making some adjustments in the theory. Quine states that the possibility of confirming the theory by making some adjustments holds for all theories: “any statement can be held true come what may, if we make drastic enough adjustments elsewhere in the system” (Quine 40). This means that any theory can be confirmed with some drastic adjustments because we cannot be certain of the theory’s falsity, or we might not be able to show its falsity, and the adjustments made can make it accepted as true. In addition to that, because of the same reason, the reason being the ambiguity of where the error lies, no theory is immune to revision or investigation (Quine 40). Any theory can be faced with the danger of revision or investigation no matter how much support it has or how confidently it is believed to be true. Since any theory’s truthness can be obtained by making some adjustments, or shown by a newly proposed theory, no theory should be regarded as true beyond any doubt.

The law of excluded middle in logic might be given as an example to the idea that no theory can be conclusively regarded as true. The law of excluded middle states that either a proposition, or the negation of that proposition, is true. In other words, it states that there is no third option, or a middle way. However, quantum mechanics is a field where that is not quite the case; the law of excluded middle does not work properly in quantum mechanics. For instance, the thought experiment proposed by Richard Feynman in *The Feynman Lectures on Physics* (sec. 4–5), and with the later experiments done by Akira Tonomura et al. (Tonomura et al. 120), it is shown that it is not only a thought experiment, the theory that electrons pass through both of the slits on a wall in front of them, rather than passing through one of the slits is not compatible with the law of the excluded middle. It is shown with the experiments conducted by Akira Tonomura et al. that an electron passes through either one or the other of the two slits on a wall in front of it is not a true statement. This is because of electrons’ another property which also is not compatible with the law of excluded middle. That property of electrons is that they behave differently when they are observed and when they are not observed. That is to say that the statement that electrons behave as particles or waves, one of the two is true is also not a true statement because they can behave as both under different circumstances.

Similar instances to electrons' behavior in quantum mechanics and them causing the law of excluded middle not working properly support Quine's views regarding that no theory is immune to revision. If even the law of the excluded middle is a theory that is not immune to revision or investigation, no theory's truthness is certain beyond any doubt and no theory is immune to revision.

2.4.2. How Quine's Interpretation is Different from Duhem's Interpretation

Paul Needham in his article "Duhem and Quine" asserts that Quine applies the non-separability idea to a broader area than Duhem (Needham 109). Needham does not use the notion non-separability though, he uses "holism" notion to show their view regarding that statements in a system can only be evaluated as a group, not individually. Holism notion is similar in that aspect to the notion of non-separability. Needham then states that the boundaries of Duhem's claims are mathematics on one side, and truths that are gathered from experiences of everyday life on the other. Mathematics contains truths that are invulnerable to how they are applied in science and the consequences of their application. This means that even though there is a problem occurred in a scientific system, the mathematical equations used in that system are not affected by the problem, they continue to be true. The truths gathered from experiences of everyday life, on the other hand, are truths such as "the sun sets in the west," and they can withstand the attacks of "scientific rigour" directed to them (Needham 109–110). Quine's theory questions the boundary that is drawn by mathematics, even though they agree on the subject of truths gathered from experiences of everyday life. We can see Quine's questioning of mathematics in his dogmas, especially the dogma about the distinction between analytic and synthetic statements. That is why Needham is right when he states that Quine's ideas regarding non-separability are applied to a broader area than Duhem's ideas on non-separability.

Roger Ariew, similar to Needham, also talks about the differences between the thoughts of Duhem and Quine. He says that Quine's theory is also called "underdetermination" by some (Ariew, "The Duhem Thesis" 313). Underdetermination theory claims that there might exist an indefinite number of theories that are sufficiently compatible with the data acquired as a result of observation and we cannot make a rational choice between them. In addition, as it is also said by Quine, any theory can be saved in the face of a conflicting evidence by making some drastic adjustments elsewhere in the system. Ariew states that the underdetermination theory and the theory proposed by Quine are combined with the theory proposed by Duhem, and they are examined and called as being the Duhem thesis, or Duhem-Quine thesis; and some of the scholars of philosophy of science claim that they have an answer to the combined thesis (Ariew, "The Duhem Thesis" 313).[6] However, Ariew states that the ideas attributed to Duhem in those articles which the solutions refer to the combination of the theories of underdetermination, Quine, and Duhem, are not the ideas that are proposed by Duhem. He even states that Duhem "himself would not have been able to recognize what is attributed to him," (Ariew, "The Duhem Thesis" 313) meaning that some of the scholars claiming that they solved the Duhem Problem are mistaken because what they allegedly solved is not the Duhem Problem.

In his article, Ariew says that the theory, which became known as the Duhem Thesis together with Quine's ideas, consists of two parts (two subtheses). The two parts are: (i) since empirical statements are interconnected, they cannot be singly disconfirmed, (Ariew, "The Duhem Thesis" 315) that is, empirical statements cannot be individually disconfirmed or falsified on their own because they are related to each other; and (ii) if we wish to hold a particular statement true we can always adjust another statement, (Ariew, "The Duhem Thesis" 315) meaning that if we want any statement to be true,

[6] For more information regarding the scholars mentioned by Ariew see Noretta Koertge and her 1978 article "Towards a New Theory of Scientific Inquiry," Karl Popper and his 1962 book *Conjectures and Refutations*, and Clark Glymour and his 1976 article "Relevant Evidence."

we can achieve it by editing another statement and making changes to that statement. Ariew says that although Quine ascribes only the first of these two subtheses (i) to Duhem, Duhem could have regarded the first subtheses as a stepchild, or perhaps an indirect result, of his own ideas, but he would not have accepted both of the subtheses formulated thusly (Ariew, “The Duhem Thesis” 315).

Duhem has an opinion about subthesis (ii) such that when a disagreement occurs between the result of the experiment and the scientist’s prediction, what is disconfirmed is not clear (Duhem, *The Aim and Structure* 185), which is not exactly equivalent to subthesis (ii). Duhem does not say that we can show the statement we want as true by making changes in other statements, rather he says that we cannot know from where the problem originates.

Ariew introduces two concepts to explain the two aspects of the Duhem problem, which he calls non-separability and non-falsifiability (Ariew, “The Duhem Thesis” 318). He explains non-separability by saying “no theoretical hypothesis of physics by itself has observational consequences,” (Ariew, “The Duhem Thesis” 318) and non-falsifiability by saying “no theoretical hypothesis of physics can be conclusively falsified by observations alone” (Ariew, “The Duhem Thesis” 318). If we take a look back at (i) and (ii), we can see that (i) includes both non-separability and non-falsifiability concepts in itself. It can be seen that (ii) is an independent subthesis on its own. We can use Duhem’s own words in order to clarify the situation. Duhem states:

> the physicist can never subject an isolated hypothesis to experimental test, but only a whole group of hypotheses; when the experiment is in disagreement with his predictions, what he learns is that at least one of the hypotheses constituting this group is unacceptable and ought to be modified; but the experiment does not designate which one should be changed. (Duhem, *The Aim and Structure* 187)

Here, Duhem addresses ideas similar to what Ariew calls non-separability and non-falsifiability. And we can say that (i) is clearly in line with what Duhem states here. But, there is no direct relation between what Duhem states and (ii). Therefore, we can say that the difference between the Duhem problem and the Duhem-Quine thesis is the second part of the Duhem-Quine thesis, (ii), which is the addition of Quine.

2.5 Concluding Remarks

The idea shown by Needham regarding the differences of thought between Duhem and Quine on the subject of mathematics, and consequently on the subject of probability, is one of the reasons why I chose the Duhem Problem and focus on it. The reason here is that in a situation where a solution is proposed to the Duhem Problem by using Bayesian probability, determining of the viability of the solution would be more feasible. That is not quite the case in Quine's theory because even if a solution is proposed to it by using Bayesian probability, because he does not share Duhem's views on the subject of mathematics and thought that the verification of a statement in mathematics also is not conclusively certain, it makes it difficult to evaluate the proposed solution.

Another reason why I focus on the Duhem Problem is the notion of non-falsifiability arising as a direct result of non-separability. Non-falsifiability is different in Quine's theory from Duhem's. Even though Quine states that no statement is immune to revision or re-evaluation, he also claims that any theory can be verified if some necessary adjustments are made elsewhere in the system. I think that the verification thought on Quine's theory is somewhat different than what Duhem proposes because Duhem focuses on theories being falsified rather than them being verified.

Duhem states that in a system of theories when one encounters an error, she cannot find from where exactly in the system the error is caused because she cannot evaluate the theories individually and independent from the other theories. That is why she cannot determinately locate which theory is the cause of error, which part of the system needs to be changed or abandoned. Quine, on the other hand, states that since all theories in the system are connected to each other, the scientist cannot locate the exact place of the problem when the scientist encounters a problem, that is why any theory can be accepted as true if the scientist make some changes elsewhere in the system. In addition to that, Quine also states that no statement is exempt from revision or re-evaluation. Therefore, both in Duhem’s and Quine’s theories contains something similar to non-separability but as a direct result of non-separability, Duhem remarks the non-falsifiability of theories, while Quine points out the possibility of theories being verified by making some adjustments.

CHAPTER 3

BAYESIAN EPISTEMOLOGY

In this chapter of the thesis, I will mainly focus on Bayesian Probability. First, I will give some information regarding Probability Calculus in order to make things clearer. I will explain some of the notions and axioms in probability calculus that are crucial to understanding Bayes' theory of probability. After I introduced the necessary notions and axioms in probability calculus, I will explain Bayes' Theorem. Even though the theorem has multiple forms, and I will provide information regarding three of the forms, I will mainly use the first formulation of it to explain what the theorem means.

In the second part of the chapter, I will focus on Colin Howson and Peter Urbach's solution proposed in their book *Scientific Reasoning: The Bayesian Approach (1993)*. They claim in their book that the Bayesian Probability, more specifically the Personalistic Bayesian Probability, can solve the Duhem Problem. They state that even though theories used as a group are falsified, their individual probabilities are changed. These changes refer to Bayes' theorem and can be explained by the Personalistic Bayesian Probability (Howson and Urbach 108). I will examine whether their claim is viable or not. Upon examination, I will also investigate some examples Howson and Urbach use to defend their claim. One of the examples is a paradox pointed out by Carl Hempel called Ravens Paradox (Hempel 11). The paradox is a good example to show that there are different degrees of confirmation and disconfirmation; not all evidence affects a theory the same.

The other example I will investigate is about the calculation of the atomic weight of the elements. The example is used to explain that even though the posterior probabilities of statements are reassigned, the result would not change drastically. If the statement's probability of being false is considerably high, then the statement is highly likely to be false even after the probabilities are reassigned. The same holds for the scenario of a statement being true.

After I investigate Howson and Urbach's solution to the Duhem Problem, I will address some possible objections that might be raised against Howson and Urbach's solution and I will provide some possible responses to those objections.

3.1. Probability Calculus

It is important to mention some notions of the Bayesian epistemology with respect to how concepts such as evidence and theory, or hypothesis, is understood, since these notions are among the fundamental parts of science and scientific reasoning (Howson and Urbach 91). There are four probability axioms needed to be addressed: Let P be a probability function, $P(a)$ be the probability of a, $P(t)$ be the probability of t representing something true, $P(a \vee b)$ be the probability of a or b, $P(a \wedge b)$ be the probability of a and b, $P(a \mid b)$ be the conditional probability of a given b, and the symbol $\perp$ denote falsity;

1) $P(a) \geq 0$ for all a,
2) $P(t) = 1$,
3) $P(a \vee b) = P(a) + P(b)$ for all a and b such that $a \wedge b \leftrightarrow \perp$, and
4) $P(a \mid b) = P(a \wedge b) / P(b)$ where $P(b) \neq 0$ (Howson and Urbach 16).

The first axiom means that a probability cannot be negative; and the probability of something false is zero. The second one shows that the probability of something true is one. Hence, combining the first two axioms, one can conclude that the probability of an event has a value between 0 and 1. It should be noted that the first three axioms are sufficient to deal with unconditional probabilities, meaning that the occurrence of an event without depending on any other event's occurrence. However, in order to deal with conditional probabilities, meaning that the occurrence of an event depends on another event's occurrence, the fourth axiom is also needed. Furthermore, unconditional probabilities are also referred as "prior probabilities," and conditional probabilities as "posterior probabilities" (Howson and Urbach 21). From now on, I shall refer to them as "prior probabilities" and "posterior probabilities," respectively.

Here, some theorems that are important and necessary to understand how Bayes' Theorem is formulated might need to be addressed here. I will not provide the proofs of the theorems, but all can be proven with the help of the axioms mentioned above and some other theorems that can also be proven by those axioms. For more detailed information regarding the proofs of the theorems I will address, and other related theorems used in their proofs, one can look at the *Probability Calculus* chapter of Howson and Urbach's book *Scientific Reasoning: The Bayesian Approach*. The theorems are:

> T1) If a entails b, then $P(a) \leq P(b)$.
>
> T2) If a_i entails $\sim a_j$, where $1 \leq i < j \leq n$, then $P(a_1 \vee \ldots \vee a_n) = P(a_1) + \ldots + P(a_n)$.
>
> T3) For any proposition b, if $P(a_1 \vee \ldots \vee a_n) = 1$, and a_i entails $\sim a_j$ when $i \neq j$ and $P(a_i) > 0$, then $P(b) = P(b \mid a_1)P(a_1) + \ldots + P(b \mid a_n)P(a_n)$. (Howson and Urbach 17–19).

Now we can move to Bayes' Theorem. Bayes' Theorem has various forms, but I will firstly mention the first formulation in Howson and Urbach's book (Howson and Urbach 20–21). The first form of Bayes' Theorem is:

B1) $P(h \mid e) = P(e \mid h)\, P(h) \,/\, P(e)$, where $P(h)$ and $P(e)$ is greater than 0 (Howson and Urbach 20).

Here, the letter h stands for hypothesis and the letter e stands for evidence, $P(h \mid e)$ stands for the posterior probability of the hypothesis, and $P(e \mid h)$ stands for the *likelihood* of the hypothesis (Howson and Urbach 20). The relations between a hypothesis and evidence, and how a hypothesis is confirmed by evidence can be explained in terms of their probabilities by saying:

if *P(h)* measures your belief in a hypothesis when you do not know the evidence, and *P(h | e)* is the corresponding measure when you do, e strengthens your belief in *h* or, we may say, confirms it, just in case the second probability exceeds the first. We refer in the usual way to *P(h)* as 'the prior probability' of *h*, and to *P(h | e)* as the 'posterior probability' of *h* relative to, or in the light of *e* (Howson and Urbach 91–92).

In other words, if *P(h | e) > P(h)*, it means that *e* confirms or supports *h*. If *P(h | e) < P(h)*, then *e* disconfirms *h*. Finally, if *P(h | e) = P(h)*, then it means that *e* does not have an effect on *h*, *e* is neutral towards *h*. Furthermore, if *P(h | e) > P(h | e') > P(h)*, the first set of evidence, *e*, supports the hypothesis *h* more than the second set of evidence, *e'* (Howson and Urbach 92).

The first form of Bayes' theorem means that the posterior probability of a hypothesis depends on three probabilities: *P(e | h)*, *P(e)*, and *P(h)*. Therefore, if one knows the values of these three, then she can calculate *P(h | e)*, or show the relation between *e* and *h*, whether the evidence confirms or disconfirms the hypothesis or does not have an effect on the hypothesis. The dependence of the posterior probability on these three terms implies "the more probable the evidence, relative to the hypothesis, the more that hypothesis is confirmed" (Howson and Urbach 92). This means that the value of the probability of the evidence directly affects the value of the posterior probability of the hypothesis. For instance, if *e* refutes *h*, then the evidence disconfirms the hypothesis at a maximum degree and *P(e | h)* is 0. Confirmation at a maximum degree occurs when the hypothesis logically implies the evidence and *P(e | h)* is 1. Another implication of this dependence is that there is an inverse relation of dependence between *P(h | e)* and *P(e)*, meaning that when the value of *P(e)* decreases, the value of *P(h | e)* increases. Therefore, one might say that the more surprising the evidence, the more confirmation it provides to the hypothesis (Howson and Urbach 93).

We can also use another notation for the first form of Bayes' Theorem by using (T3) and replacing *P(e)* with *P(e | h)P(h) + P(e | ~h)P(~h)*. In other words, if we do not have any immediate value for $P(e)$, or we cannot directly calculate it, we can calculate its value by using its relation to the hypothesis and the negation of the hypothesis. Therefore, the theorem reforms to:

B1(i)) $P(h \mid e) = P(e \mid h)\, P(h) / (P(e \mid h)P(h) + P(e \mid {\sim}h)P({\sim}h))$.

The second form of Bayes' Theorem is:

B2) $P(h_k \mid e) = P(e \mid h_k)P(h_k) / \Sigma^{n}_{i=1}P(e \mid h_i)P(h_i)$.

And the third form of Bayes' Theorem is:

B3) $P(h \mid e) = P(h) / [P(h) + (P(e \mid {\sim}h) / P(e \mid h))P({\sim}h)]$ (Howson and Urbach 21).

The second form of Bayes' Theorem (B2) can be seen as a more general formulation of (B1(i)), when h_i entails ${\sim}h_j$ and $i \neq j$. The third form (B3) is an important formulation for the cases where we have information regarding the conditional probability of the evidence *e* to both the hypothesis *h* and the negation of the hypothesis *h*, which is ${\sim}h$. Here, $P(e \mid {\sim}h) / P(e \mid h)$ is called the *likelihood ratio* (Howson and Urbach 22). An example that is in a similar nature to the *Harvard Medical School Test*[7] can be created in order to show the usage and importance of (B3). Let us assume that there exists a disease called *fading*, *F* for short, and a test to determine whether a person has *fading*, called *mithrilisation*, *M* for short. *M* shows whether a person has the disease or not. When the result of *M* is positive, it indicates that the person has the disease, and when the result is negative, it indicates that the person does not have the disease. However, the result of the test *M* is not always accurate. Let us assume that even though the test never gives a false negative outcome, meaning that it shows negative when the person has *fading*, in one in ten cases it gives a false positive outcome, meaning that it shows positive when the person does not have *fading*. Thus, the chance of a person having a false positive result of *M* is 10%. Let us also assume that the incidence of *F* in the

[7] For more information, see Casscells, Schoenberger, and Grayboys' 1978 article "Interpretation by Physicians of Clinical Laboratory Results."

population is one in one hundred. In this case, what is the probability of a randomly selected person having *F* when she gets the test *M* and *M* shows a positive outcome?

At first glance, one might think that the probability of that person having *F* might be 90% since *M* has 10% chance of having a false positive result. However, there are some things that is not taken into consideration, such as the incidence of *F*. Let us write some of the probability values that are important to calculate the probability of a person having *F*. Now, we said that there is 10% chance of *M* giving a false positive result, so *M* has 0,9 probability of giving the correct result. The incidence of *F* in the population is 1%, so the probability of a person having *F* is 0,01; this means that the probability of a person not having *F* is 0,99. Therefore, we can see:

(i) $P(M / \sim F) = 0{,}1$.

(ii) $P(\sim M / F) = 0$.

(iii) $P(F) = 0{,}01$, and $P(\sim F) = 0{,}99$.

(iv) $P(M / F) = 1$ since $P(M / F) = 1 – P(\sim M / F)$.

When we put those probability values into (B3), we can calculate the probability of a randomly selected person having *F* when she has a positive result of the test *M*, meaning that we can calculate $P(F / M)$. And when we calculate $P(F / M)$ by using (B3), we can conclude that $P(F / M) = 0{,}09$. As it can be clearly seen, the result is significantly different from the initial thought that the probability of having *F* when having a positive outcome of *M* is 0,9. This is because there are variety of other factors that need to be considered, apart from *M* showing a correct result, in order to correctly calculate the probability, such as the incidence of *F* in the population etc. That is why Bayes' Theorem is an important and useful tool to calculate the probability of a case by taking various instances into consideration, all of which are crucial to calculate the probability correctly.

Having mentioned some axioms and theorems of the probability calculus and showing various formulations of Bayes' Theorem, and providing some information regarding how they can be used, we can now move on to discuss Colin Howson and Peter Urbach's Bayesian solution to the Duhem Problem.

3.2. Howson & Urbach's Bayesian Solution to the Duhem Problem

Bayesian Probability shows that the evidence obtained as a result of the experiment is an important data for revealing the reliability or accuracy of a theory. In order to find the posterior probability of a theory, in addition to the prior probability of the theory, the relationship of the theory with the gathered evidence is also important. However, this does not mean that experimental evidence definitively determines the likelihood of the theory. Bayesian Probability is used to determine in which direction experimental evidence changes the probability of the theory being true or false. In other words, the use of experimental evidence in probability calculation is not a situation that indicates the existence of crucial experiments. Howson and Urbach, while explaining their solutions, say that there is experimental evidence that provides different degrees of confirmation or refutation, but they do not mention the existence of evidence that definitively shows the correctness of a theory.

The same may not always be the case about the refutation of a theory. For some theories, an evidence that disproves the theory, a counterexample may mean its falsification. For example, when a proposition such as "all emeralds are green" is put forward, seeing a green emerald does not necessarily indicate that the proposition is correct, but seeing a blue emerald is enough to show that the proposition is wrong. This is because if we say that the proposition "all emeralds are green" is h, and seeing a green emerald is e, seeing a blue emerald would be $\sim e$ and $P(e \mid h) = 1$, and $P(h \mid \sim e) = 0$. And unless a situation arises that will cause us to revoke $\sim e$, another evidence cannot confirm h because in a situation where e' is another evidence which is logically consistent with $\sim e$, $P(h \mid \sim e \wedge e')$ would also be zero. However, seeing a blue emerald is not a definitive proof that a proposition other than the "all emeralds are green" proposition is true. In other words, although experimental evidence is not sufficient to definitively show the accuracy of a theory, it can be used to determine its degree of confirmation.

How is evidence used to determine the degree of confirmation of a theory? Let us say that evidence e is an evidence that confirms the hypothesis h. So, it is an expected situation that the result e emerges as a result of h. In other words, h entails e. This means that $P(e \mid h) = 1$. In that case, if we rewrite (B1) by using the information we have the equation turns into $P(h \mid e) = P(h) / P(e)$. Therefore, we can also see from there that $P(h \mid e) > P(h)$, meaning that e confirms h.

In order to say that an evidence confirms a theory, shouldn't a test be done indefinitely and give the same result in all of them? Howson and Urbach explain why a theory does not need to be tested endlessly. They say that if we have more than one similar evidence, say $e_1, e_2, \ldots, e_n$, the power of the evidence gets smaller (Howson and Urbach 94). That result in that even though $P(h \mid e_1 \wedge e_2 \wedge \ldots \wedge e_n) \geq P(h \mid e_1 \wedge e_2 \wedge \ldots \wedge e_{n-1})$, as n gets closer to infinity, these two probability values get closer to each other because their limits are equal to each other, meaning that $limP(h \mid e_1 \wedge e_2 \wedge \ldots \wedge e_n) = limP(h \mid e_1 \wedge e_2 \wedge \ldots \wedge e_{n-1})$ (Howson and Urbach 94). Therefore, in order to say that an evidence confirms a theory, there is no need for endless tests with the same result. However, it should be said that Bayesian Probability does not give a conclusive result about when the scientist should stop testing, the decision is related to the scientist's trust in the result.

Does not the claim that the evidence obtained after a test has a limit of confirmation power, even if the test is repeated indefinitely, mean that the evidence can only confirm the theory up to a point? If that is the case, what do we need to do to get a higher degree of confirmation? We need to perform other tests, the results of which are predicted by other parts of the theory, and use the confirming power of the evidence obtained as a result of those tests. Thus, we increase the probability of the theory being true. However, this also increases the theory's confirmation up to a certain point, so there is a limit again. In order to show why that is the case, let us say that the proposition “all emeralds are green” is h and a more restricted version of h, say “all emeralds in region x are green” is h_x. Since h entails h_x and h_x handles a more restricted situation, we can say that the probability of h_x is bigger than the probability of h, so $P(h) \leq P(h_x)$.

When we observe a green emerald in the region x, it confirms both h and h_x. If we say that those observations are $e_1, e_2, \ldots, e_n$, since those observations confirm both h and h_x, then $P(e_1 \wedge e_2 \wedge \ldots \wedge e_n \mid h) = 1$ and $P(e_1 \wedge e_2 \wedge \ldots \wedge e_n \mid h_x) = 1$. In this case, if we use (B1), we obtain: $P(h \mid e_1 \wedge e_2 \wedge \ldots \wedge e_n) = P(h) / P(e_1 \wedge e_2 \wedge \ldots \wedge e_n)$ and similarly $P(h_x \mid e_1 \wedge e_2 \wedge \ldots \wedge e_n) = P(h_x) / P(e_1 \wedge e_2 \wedge \ldots \wedge e_n)$. Since $P(e_1 \wedge e_2 \wedge \ldots \wedge e_n)$ is common in those two equations, when we combine the two equations, we obtain the equation $P(h \mid e_1 \wedge e_2 \wedge \ldots \wedge e_n) = (P(h) / P(h_x))\, P(h_x \mid e_1 \wedge e_2 \wedge \ldots \wedge e_n)$. As we can see from there, even if the green emeralds we observed in the region x make the posterior probability of h_x 1, the posterior probability of h is limited by the prior probability of h_x. In other words, a more restricted version of h or a version of h confirmed by the same evidence sets a limit for the confirmation value of h (Howson and Urbach 94–95). The same holds for the situation that the gathered evidence disconfirms h or h_x. Therefore, when we obtain disconfirming evidence, we can calculate how much the probability of our theory has decreased by using the parts in it. This means that although the theories are related to each other, we can determine how their probabilities have undergone a change by using this connection in the light of evidence.

One of the aspects of the solution proposed by Bayesian Probability to the Duhem problem focuses on the notion of Bayesian Probability that there are different degrees of confirmation and refutation regarding hypotheses and evidence. An example of this notion can be shown by providing a Bayesian solution to the Ravens paradox. The paradox is about the confirmation of the hypothesis "all ravens are black." It is stated why the ravens paradox is called a "paradox" is because observing something which is a non-black non-raven provides confirmation to the hypothesis, just as observing a black raven providing confirmation to it. This may lead one to a misconception to suggest that "you could investigate that and other similar generalizations just as well by examining objects on your desk as by studying ravens on the wing" (Howson and Urbach 100). However, according to Bayesian epistemology, two different data both confirming a hypothesis does not mean that they confirm it equally. There is a degree of confirmation between them. In the case of the ravens paradox, Bayesian solution to the ravens paradox shows that there are degrees of confirmation regarding a hypothesis and evidence. Seeing something non-black non-raven does not contribute to the hypothesis to the same degree as finding a black raven.

Let us examine why the contribution of seeing something non-black non-raven and seeing a black raven are not the same. According to Howson and Urbach, the paradox arises from two assumptions regarding confirmation:

1) Hypotheses of the form "All *R*s are *B*" are confirmed by evidence of something that is both *R* and *B*.
2) Logically equivalent hypotheses are confirmed by the same evidence (Howson and Urbach 100).

Here, we can see that by using the two assumptions the propositions "All non-*B*s are non-*R*s" and "All *R*s are *B*" can be confirmed by observing something that is non-*R* and non-*B* (for the sake of simplicity, from now on observing something that is both black and a raven will be referred to as *RB*, and observing something that is both non-black and a non-raven will be referred to as *~R~B*). The reason why the two propositions are confirmed by *~R~B* is because they are logically equivalent. Be that as it may, the two propositions both being confirmed by *~R~B* does not mean that their confirmation are to the same degree. Furthermore, we can say that the proposition "all ravens are black" are not confirmed to the same degree by *RB* and *~R~B*. We can show this by using (B1):

(i) $P(h \mid RB) / P(h) = P(RB \mid h) / P(RB)$

(ii) $P(h \mid {\sim}R{\sim}B) / P(h) = P({\sim}R{\sim}B \mid h) / P({\sim}R{\sim}B)$ (Howson and Urbach 100).

We can make some derivations and simplifications in these equations. For instance, instead of $P(RB \mid h)$ we can write $P(B \mid h \wedge R)P(R \mid h)$ because the probability of observing something that is a black raven is also the probability of observing something that is black on the condition that *all ravens are black* and that something is a raven, and the probability of that something is a raven on the condition that *all ravens are black*. If our conditions are the hypothesis that *all ravens are black* and that something is a raven, then that something is black; therefore, $P(B \mid h \wedge R) = 1$. Furthermore, we can say that something being a raven is not conditional to the claim that *all ravens are black* because something being a raven is not dependent on that claim; that is why we can write *P(R)* instead of *P(R | h)*. Therefore, we can simply write *P(R)* instead of *P(RB | h)* (Howson and Urbach 101). By the same reasoning, we can write *P(~B)* instead of *P(~R~B | h)*. Then, if we use the *axiom (4)*, (i) and (ii) turns into *P(h | RB) / P(h)* = 1 / *P(B | R)*, and *P(h | ~R~B) / P(h) = P(~R | ~B)* respectively.

For (i), the posterior probability of *h* has an inverse relation with the probability of seeing something black on the condition that that something is a raven. If the prior probability of all ravens being black were high, then seeing a black raven would only increase the posterior probability to a small degree. But if the prior probability of all ravens being black were not that high, meaning that it is also relatively probable that all ravens are not black, seeing a black raven would significantly increase the posterior probability of *h*. For (ii), on the other hand, the posterior probability of *h* has an inverse relation with the probability of seeing something that is not a raven on the condition that that something is not black. Here, even if we are convinced that none of the ravens are black, since we can safely assume that there are uncountably many things that are not black, the number of ravens in the set of things that are not black would be significantly small. So the probability of observing something that is not black and also not a raven would be significantly close to 1. As a result, observing something non-black non-raven would not make a significant change in the probability of *h*; the posterior and prior probabilities of *h* would be essentially same.

Another focus of Howson and Urbach's solution is that the probability of one theory can also be calculated in relation to other theories, so that it can be determined which theory is the highest probable cause of error. This is because even though the main theory of the system encounters with disconfirming evidence, or a false prediction, “logic does not compel us to regard the principal theory as untrue, since the error may lie in one or more of the auxiliaries” (Howson and Urbach 105). This is an important part of their proposed solution because their focus in the Duhem problem is “when several distinct theories are involved in deriving a false prediction, which of them should be regarded as false?” (Howson and Urbach 105). Howson and Urbach claim that the questions raised by the Duhem Problem can be solved by “referring to Bayes's theorem and considering how the individual probabilities of theories are severally altered when, as a group, they have been falsified" (Howson and Urbach 108). In addition, one of the situations that is produced by Howson and Urbach's solution is that although some prior probabilities are determined by the scientist based on the data at hand, and therefore not always exactly accurate, the variation of these prior probabilities does not lead to large differences in the result obtained.

Another example, which can be called the atomic weight example, presented by Howson and Urbach is their main example, which they use to illustrate their solution to the Duhem problem. The reason for this is understandable, because it both offers a solution that can answer the question of which theory should be abandoned, and also answers some objections that may be raised about prior probabilities. In addition to these, I think it also provides assistance in evaluating theories individually or together with other theories.

The atomic weight example is given by Howson and Urbach regarding the Bayesian solution to the Duhem problem in order to show that different hypotheses that are disconfirmed or refuted by evidence can be disconfirmed or refuted to very different degrees. The example concerns with some calculations regarding atomic weight of an element. The example uses the idea of William Prout that all matter is formed from different combinations of a basic element, for Prout it was hydrogen; and that is why Prout proposed another idea that the atomic weight of all elements are "whole-number multiple[s] of the atomic weight of hydrogen" (Howson and Urbach 108).[8] When confronted by some disconfirming evidence, when he calculated the atomic weight of the element chlorine as 35,83 for instance, rather than abandoning his idea about hydrogen, he changed the value of the atomic weight of chlorine to 36, which is the nearest whole number. Similarly, Thomas Thomson calculated the atomic weight of hydrogen as 0,125, and when he encountered with observational data showing the atomic weight of the element boron as 0,829, he changed the value to 0,875 in order

[8] For more information, see William Prout's 1815 and 1816 articles "On the Relation Between the Specific Gravities of Bodies in Their Gaseous State and the Weights of Their Atoms," and "Correction of a Mistake in the Essay on the Relations Between the Specific Gravities of Bodies in Their Gaseous State and the Weights of their Atoms."

for it to be a multiple of the atomic weight of hydrogen (Howson and Urbach 108).[9] The behaviors of Prout and Thomson indicate that when the scientist encounters with a disconfirming evidence, whole system of ideas of the scientist will not be abandoned. The scientist will rather adjust the data according to the system, or try to find a hypothesis within the system, which is not a core hypothesis and easier one to abandon, to eliminate the error.

Bayesian probability can help us understand whether Prout and Thomson were right to not abandon their ideas when encountering disconfirming evidence or not. Let us say that Prout's hypothesis, with the combination of an appropriate assumption such that the measuring techniques and the purity of the chemicals used are accurate, confronts evidence showing the atomic weight of the element chlorine as 35,83. It can be seen that the evidence cannot be compatible with the combination of the hypothesis and the assumption since the evidence disconfirms either the hypothesis or the assumption, or both. In order to determine how their confirmation values change, and which of them should be more likely to be reevaluated or changed, we can use Bayesian probability. Here, let t refer to the hypothesis of Prout, a refer to the appropriate assumption, and e refer to the evidence. Furthermore, $P(t)$ refers to the prior probability of t, $P(a)$ refers to the prior probability of a, $P(e)$ refers to the probability of e, $P(t \mid e)$ refers to the posterior probability of t given e, $P(a \mid e)$ refers to the posterior probability of a given e, $P(e \mid t)$ refers to the likelihood of e given t, and $P(e \mid a)$ refers to the likelihood of e given a. By using (B1) we can write:

for t) $P(t \mid e) = P(e \mid t)P(t) / P(e)$,

for a) $P(a \mid e) = P(e \mid a)P(a) / P(e)$.

Now let us begin by determining the prior probabilities of t and a. Howson and Urbach states that Prout's hypothesis was regarded as true by many scholars and the confidence in its truth was extremely high (Howson and Urbach 109). That is why we can estimate the prior probability of t as a considerably high value, say 0,9. For the

[9] For more information, see Thomas Thomson's 1818 article "Some Additional Observations on the Weights of the Atoms of Chemical Bodies."

appropriate assumption regarding the tools or chemicals used, on the other hand, the confidence was not as high as Prout's hypothesis. This is because the margin of error of the tools to measure the weight were high, and the purity of the chemicals were sometimes questionable. That is why the measurements of atomic weight did not always provide the same results (Howson and Urbach 109). Therefore, we should make an estimate of the prior probability of *a* that is considerably smaller than 0,9 since there is a significant degree of confidence between *t* and *a*. But it should still be higher than 0,5 since the tools and chemicals mentioned in *a* are still being used and that is why the probability of *a* being true should be higher than the probability of *a* being false. So let us assume that the prior probability of *a* is 0,6.

Let us now move on to determine the probability values related to *e*. By using (B1(i)) we can write $P(e \mid t)P(t) + P(e \mid {\sim}t)P({\sim}t)$ instead of $P(e)$. By the same reasoning, we can write $P(e \mid t \wedge a)P(a \mid t) + P(e \mid t \wedge {\sim}a)P({\sim}a \mid t)$ instead of $P(e \mid t)$. In addition, we can write $P(a)$ instead of $P(a \mid t)$ and $P({\sim}a)$ instead of $P({\sim}a \mid t)$ because the value of the accuracy of the tools and the purity of the chemicals are not related to the value of the hypothesis of Prout. Since we know that the combination of *t* and *a* is refuted by *e* (Howson and Urbach 111), we should note that $P(e \mid t \wedge a) = 0$. As a result, we can write that $P(e \mid t) = P(e \mid t \wedge {\sim}a)P({\sim}a)$. If we apply the reasoning we used in $P(e \mid t)$ to $P(e \mid a)$, we get: $P(e \mid a) = P(e \mid {\sim}t \wedge a)P({\sim}t)$. Also, we get: $P(e \mid {\sim}t) = P(e \mid {\sim}t \wedge a)P(a) + P(e \mid {\sim}t \wedge {\sim}a)P({\sim}a)$. Afterwards, we should estimate the values of $P(e \mid {\sim}t \wedge a)$, $P(e \mid {\sim}t \wedge {\sim}a)$, and $P(e \mid t \wedge {\sim}a)$. All three of the values should be rather small because both *t* and *a* are more probable to be true than false, and since the probability of *t* being true is higher than the probability of *a* being true, $P(e \mid t \wedge {\sim}a)$ should be bigger than the other two. Therefore, Howson and Urbach conjectured that the probabilities of the three are 0,01, 0,01, and 0,02, respectively (Howson and Urbach 111). Now we can calculate the other necessary probabilities for the calculation of the posterior probabilities of *t* and *a*. Those are:

$P(e \mid {\sim}t) = 0{,}01$,

$P(e \mid t) = 0{,}008$,

$P(e \mid a) = 0{,}001$,

$P(e) = 0{,}0082$.

Then, it can be calculated that the posterior probability of *t*, $P(t \mid e)$, equals to 0,878, and the posterior probability of *a*, $P(a \mid e)$, equals to 0,073. Keep in mind that their prior probabilities were 0,9, and 0,6, respectively. Hence, one can see that the evidence's disconfirming effects on the hypothesis and the assumption are significantly different since the change in the probability of the hypothesis is considerably small, while the probability of the assumption has changed drastically. Therefore, the atomic weight example shows that we can calculate to what degree an assumption is viable compared to the hypothesis. Also, we can say that by using Bayesian probability we can determine which part of the theory is more likely to be the cause of error and should be readjusted or changed.

It might be said that some prior probabilities are chosen, and they may not be exact, but Howson and Urbach show that it would not matter if we assigned other values of prior probabilities. The calculations show similar results. For instance, if the prior probability of the hypothesis *t* would be 0,7 and other values are not changed, the posterior probability of the hypothesis, $P(t \mid e)$, would be equal to 0,65, and the posterior probability of the assumption *a*, $P(a \mid e)$, would be equal to 0,21. Therefore, one can conclude that the hypothesis "is still more likely to be true than false in the light of the adverse evidence, and the auxiliary assumptions are still much more likely to be false than true" (Howson and Urbach 113). Thus, the results do not change drastically even if we reassign the values of the prior probabilities.

I believe that the Bayesian solution proposed by Howson and Urbach to the Duhem problem is a viable one, but can we say it provides a solution to Duhem-Quine Thesis and not to the original Duhem problem? At this point, although Howson and Urbach deal with it as the Duhem problem, the problem they initially focused on seems more like the Duhem-Quine thesis, or at least a part of the Duhem problem, since they mainly focus on falsification and confirmation. However, we can say that their solution offers a viable solution to the original Duhem problem as well. What I mean by that is that we can say that it offers a solution for non-separability, which Duhem put forward and forms the basis of the problem. In other words, Howson and Urbach's Bayesian solution offers a solution to both the non-separability and non-falsifiability aspects of the Duhem problem.

Bayesian probability offers a solution to both non-separability and non-falsifiability because I think it allows us to evaluate theories individually. This evaluation is the individual probability values of the theories. The probability values of theories are not always independent of the other theories, but can be calculated taking the influence of other theories into consideration. In this way, we have a tool to solve the non-separability problem. The chance to evaluate the theories separately from each other, and the chance to evaluate them together with their relations with each other in cases where we cannot evaluate them separately, is the tool offered to us by Bayesian probability. On the subject of non-falsifiability, the fact that the evidence gives confirmation or disconfirmation at different degrees, that theories are affected in different degrees, and, as shown in the examples, that it can be detected that the different degrees the theories are affected, are indicators that non-falsifiability has a viable Bayesian solution.

Howson and Urbach's solution as I explained it, is not presented as a solution to the Duhem problem, because Howson and Urbach do not say that we offer a solution for non-separability. The problem they pose as the Duhem problem is closer to Duhem-Quine thesis because it focuses more on falsifiability and confirmation. And Howson and Urbach point out that they do not think that the theories are all that entangled with each other (Howson and Urbach 111). Be that as it may, I think the Bayesian Probability solution they put forward a viable solution to the non-separability part of the Duhem problem as well. The reason for this is that other theories are also used when calculating the probability of a theory, and yet each theory has individual probability values and can be calculated. However, the calculation is not exactly an addition of theories as I wrote earlier in the first chapter ($T_1+T_2+\ldots+T_n$). The reason why it is not an addition can be explained with a simple example: let us say there are ten different theories in a theory system. When we want to calculate the probability of the theory system as a whole, we cannot simply find the probability values of these ten theories and add them together, because if we consider that any probability value can be a maximum of 1, then the probability of the theory system will exceed 1. Why? Because even if we assume that the probability of the theory system is 1, if the probability values of the theories we use in our system are close to each other, the probability of each of them will be approximately 0.1, which is a significantly low probability value. Alternatively, let us say that the probability value of one theory is very high, for example 0.9, then the remaining nine theories have even lower probability values. In both cases, most of the theories have significantly higher probabilities of being false than true.

It is not difficult to say that using theories with such low probability values will do more harm than good for our theory system, because low probability value means that the probability of error or the probability of the theory system encountering problems is high. If we think that our aim is to reveal the most robust theory or theory system by reducing the possibility of error as much as possible, we should not use theories with such a low probability value. The same case holds when the number of theories in the theory system is different. This means that we cannot calculate the probabilities of theory systems by adding the probabilities of the theories used.

Then, what kind of a calculation method will we use? As we can see in the atomic weight example, we can determine thanks to the conditional probability method what kind of relation the probability values of the hypotheses we use have. This means that we can determine whether the theories or hypotheses we use are independent or connected. Bayesian probability allows us to see how probabilities change depending on each other, or whether there are independent assumptions whose probability values do not depend on each other. In addition, we can see how the probability of evidence changes within the framework of the hypotheses and assumptions with which we work. When we look at (B1(i)) version of Bayes' theorem, for instance, in order to find the posterior probability of *h*, we get the equation $P(h \mid e) = [(P(e \mid h \wedge a)P(a \mid h) + P(e \mid h \wedge {\sim}a)P({\sim}a \mid h))\ P(h)] / P(e \mid h)P(h) + P(e \mid {\sim}h)P({\sim}h)$. As it can be seen from the equation, the posterior probability of *h* does not only depend on its own prior probability, and its relation to the evidence. The posterior probability of *h* also depends on its relation to the assumption *a* and *a*'s probability values. The same holds for the posterior probability of *a*. Similarly, we can show the connection between the probability values of *h* and *a* by using (B2). In the equation $P(h_k \mid e) = P(e \mid h_k)P(h_k) / \Sigma^n_{i=1}P(e \mid h_i)P(h_i)$ if we say that *a* can be defined as being another hypothesis in the system that can be shown in $\Sigma^n_{i=1}P(e \mid h_i)P(h_i)$ part of the equation, then, again, we can say that we can calculate the probability values of hypotheses in relation to each other.

Even though Duhem states that we cannot evaluate theories separately from other theories, meaning that there is non-separability, in the light of Bayesian probability we can say that theories have individual probability values. Those probability values of each theory, however, are not always measured in isolation from other theories because the theories that are used together or in connection with other theories affect the probability values of those theories. But, again, we can still measure the probability values of individual theories, and this gives us an advantage towards the possibility of evaluating theories individually. Afterwards, considering the prior and posterior probabilities of the theories, we can make a decision regarding which theory in the system should be changed or abandoned. The decision we make might not be accurate beyond any doubt, but it would be the highest probable cause of error.

3.3. Objections to the Bayesian Solution and Responses

The objections raised against the Bayesian solution to the Duhem problem focus on two main topics. The two topics are summarized in a single sentence by Deborah Mayo: “The possibility of a degree of belief reconstruction does not help to pinpoint which element ought to be regarded as the false one” (Mayo 228). One of the topics is the non-separability problem, and the other is the assigned priors problem. Some of the critics of Bayesianism, Mayo for instance, claim that Bayesian probability does not provide an acceptable solution to the non-separability aspect of the Duhem problem (Mayo 224).

Similar to Mayo, Luc Bovens and Stephan Hartmann state that Bayesians use an independence assumption, and that assumption does not correspond to the non-separability aspect of the Duhem problem (Bovens and Hartmann 111). However, I argue that the Bayesian solution Howson and Urbach proposed offers a viable explanation to how we can tackle non-separability, and the usage of an independence assumption is limited to situations where there is probabilistic independence, which does not negatively affect the outcome.

The other topic that the objections raised against the Bayesian solution focus on is the problem of assigned prior probabilities. Some critics claim that the process of the scientist's assignment of prior probabilities is done in an arbitrary way. They state that the process is unreasonably subjective and depends too much on the scientist that the result is deemed to be uncertain.

I claim that the process of assigning priors is not as arbitrary or random as one might think, and the dependence on the scientist is not at a dangerous level. This is because assigning priors is a process in which various evidential data is taken into consideration. Moreover, the atomic weight example Howson and Urbach used is sufficient to answer some of the objections, since it shows that even though the prior probabilities are assigned differently, the result would still show that one of the posterior probabilities is significantly higher than the other.

3.3.1. Non-separability Problem

Deborah Mayo in her article "Duhem's Problem, the Bayesian Way, and Error Statistics, or 'What's Belief Got to Do with It?'" claims that the Bayesian solution to the Duhem problem fails to provide an answer to the non-separability aspect of the problem. She states that when evidence does not bear the predicted outcome of the theory, the Bayesian solution does not give us the answer to which theory should be abandoned (Mayo 224). In addition, the usage of an independence assumption in the explanation of the Bayesian solution also creates a problem with respect to non-separability because assuming that some components of the hypothesis and the assumptions are independent clashes with Duhem's thought that the theories we use cannot be separated.

It is said that since the experimental evidence we get is "determined by a hypothesis and auxiliary theories that are often hopelessly interconnected with each other," (Bovens and Hartmann 111) we cannot use the evidence to determine whether a single hypothesis is confirmed or disconfirmed independently from other hypotheses or auxiliary theories. Since we cannot use or evaluate the hypothesis and the auxiliary theory separately from each other, we cannot get rid of the possibility that "the hypothesis and the auxiliary theory really come out of the same deceitful family and that the lies of one reinforce the lies of the others" (Bovens and Hartmann 111). However, Howson and Urbach's solution does provide an answer to the non-separability problem and the usage of an independence assumption does not jeopardize the viability of the answer.

At first glance, it might appear that Howson and Urbach does not provide a solution that tackles the non-separability problem, since they use an independence assumption in some parts of their explanation, and they focus on the non-falsifiability aspect of the Duhem problem. However, even if they do not explicitly state it, their solution gives an answer to the non-separability problem.

The answer to the non-separability aspect of the Duhem problem can be given by referring to the two versions of Bayes' theorem, which are (B1(i)) and (B2). In (B1(i)), we can see that the posterior probability of one hypothesis depends on the hypothesis' relation to an assumption, or another hypothesis. In order to calculate the posterior probability of one hypothesis, one needs to calculate the conditional probabilities between the two hypotheses, and the two hypotheses' relations to the evidence. While calculating the posterior probability of one of the hypotheses, one can determine whether the two hypotheses are independent or not. The two hypotheses being independent means that their conditional probabilities are equal to their prior probabilities. The usage of an independence assumption is not a necessary part of the calculation, but it makes the calculation easier. The determination of them being independent does not threaten the viability of the solution to the non-separability problem, because the relation between the two hypotheses is still in effect when calculating their posterior probabilities. Even if we establish that they are independent, we still need to calculate the effect of their relation with respect to the evidence.

In (B2), we can calculate the posterior probability of a hypothesis by using its relation to multiple hypotheses in a system. Here, the hypotheses are somewhat different versions of themselves, some are the restricted versions of one of the hypotheses and some use only certain parts of it for instance, but they all affect each other. That is why, they are all related to each other, and they all affect the probability values of each of them. As a result, we can say that by using (B1(i)) and (B2) we can calculate the posterior probability values of hypotheses that are related to each other. Even if we use an independence assumption, we can still calculate the posterior probabilities of hypotheses with the help of their relation with respect to the evidence.

3.3.2. Assigned Prior Probabilities Problem

When scientists calculate the posterior probability of a hypothesis, the prior probability of that hypothesis needs to be assigned beforehand by the scientist. The assignment procedure is claimed to be problematically subjective and arbitrary. It is said that the assigned priors are unstable personal opinions, and they might vary "not just from person to person, but from moment to moment" (Mayo 225). If the scientist could not find a way of "assigning quantitative values to the terms in their equations in non-arbitrary ways," (Dietrich and Honenberger 345) the problem of assigned priors will continue to stay to be a weakness for the Bayesian probability. Then, if the process of assigning priors depends so much on the scientist, "[h]ow can a Bayesian objectively determine which prior to use?" (Forster 415). The concerns raised against the Bayesian probability regarding the assigned priors can be answered by saying that the process is not done randomly; the priors are not assigned in a way such that it is affected by unstable opinions or mood changes to a considerable degree. Those factors are negligible because the priors are assigned based on various reliable factors, such as the consideration of evidence for and against the hypothesis, the consideration of the accuracy of the tools used, etc. In addition, the prior probability might not have been assigned completely accurately, but it would still provide important and useful information for us. The atomic weight case is a great example of it.

Some prior probabilities may not be exact, but that does not mean that they are random or completely unreliable. Because although they are not exact, they are still determined within the framework of evidence. For example, let us say that we are going to make an estimate about the height of a random person born in Turkey. At this point, we can make a more probable estimation using certain statistical data, rather than randomly saying something such as "the person is that tall." As an example to those data, the gender of the person, the average height of the people in the country for that gender, the height of the person's parents, the average height of the people in the region where the person was born and has lived, and whether there is any medical condition that will affect the person's height can be given. Having data such as those allows us to make a much more likely and accurate estimate. Assigning prior probabilities is a similar process. The scientist takes various important evidence and data into consideration before assigning priors and tries to make the most accurate evaluation. Even then the probability value might not be completely accurate, but it can still give us a convincing outcome.

Mayo claims that the calculations of the posterior probabilities can be done in reverse with the assigned prior probabilities being reversed (Mayo 228). This means that, for instance, in the atomic weight problem, if the prior probability of the assumption was higher than Prout's hypothesis, then it would have been resulted in *h* being greatly disconfirmed while *a* being affected only to a small degree. It is true that if the prior probabilities were reversed, the posterior probabilities would also be reversed, but there is a reason why the prior probabilities are assigned that way. In the case of the atomic weight example, the reason why the assumption's prior probability is chosen rather low, 0,6, was that the tools and chemicals used were not always reliable. The measurement tools did not always provide the same results and their margin of error were high. The purity of the chemicals used was not always high enough to instill confidence or sometimes the science of chemistry was not sufficiently advanced to determine the structure of the chemicals. Prout's hypothesis, on the other hand, was regarded highly trustworthy by almost all scholars and given a fairly high prior probability, 0,9, because it would provide confidently accurate and consistent results. In a case such as the atomic weight example, saying that the priors are not assigned accurately and if they were to be reversed, the result would change would not be a powerful claim because there is a reason why the priors are assigned that way, and reversing them and the results of them being reversed would not be accurate.

Mayo's another claim is that considering a fairly high probability value for the prior probability of a hypothesis *h*, say 0,9, would not leave any other option, or an assumption *a*, a fair chance of being taken into consideration because the calculations would result in *h*'s favor. That is why, she says, the prior probability of *h* should be relatively low in order to leave a fair chance for its denial (Mayo 228). As it can be seen in Howson and Urbach's atomic weight example, Mayo's reasoning can be valuable to see how the change in prior probabilities affects the outcome, but it can also be seen that the result is quite different from what Mayo might have anticipated. The reason why she raises the concern that the prior probability of *h* is given a rather high value and it should be given a lower value in order to give a fair chance of denial is because she thinks that there would be a significant change in the values of the posterior probabilities of *h* and *a*, and the Bayesian prior probability assessment process is shown to be flawed. However, the atomic weight example shows that even if we assign a fairly low prior probability value to *h*, say 0,7, though the end result is not exactly the same with *h* having prior probability value of 0,9, but we still see that the posterior probability of *h* is significantly higher than the posterior probability of *a*, one being 0,65 and the other 0,21.

3.4. Final Remarks

Howson and Urbach focus on falsifiability and confirmation when they tackle the Duhem problem. That is why their solution to it also emphasizes the non-falsifiability aspect of the problem. In order to show how the non-falsifiability aspect of the Duhem problem can be solved, they use some examples. One of the examples is the ravens paradox and it is used to explain how different types of evidence can provide different degrees of confirmation or disconfirmation.

Another example they use is the atomic weight example and it is used to show how to calculate the posterior probability of a hypothesis. With the atomic weight example, we can see that even though the assigned prior probabilities of the hypotheses are changed, the outcome of the calculation would still be similar.

Even though Howson and Urbach's emphasis is on the non-falsifiability aspect of the Duhem problem, I believe that their solution also provides an answer to the non-separability aspect, thanks specifically to (B1(i)) and (B2) versions of Bayes' theorem. With those versions, we can see how we can use the relations between hypotheses and calculate their posterior probability values in accordance with their relations to each other.

With the help of an independence assumption, we can determine which of the hypotheses can be evaluated separately. When we cannot use an independence assumption, in the situations where the hypotheses are closely related to each other, we can use conditional probability and calculate how they affect their probability values, both with respect to themselves and the evidence at hand.

CHAPTER 4

CONCLUSION

The aim of this thesis has been to investigate the Bayesian solution that is proposed to the Duhem problem by Colin Howson and Peter Urbach and show whether the solution is viable or not. Beginning this journey, I have provided some information regarding the historical background of Duhem's academic career and his studies because I believe that those information are beneficial to understand how Duhem's perspective on science had developed. Then, I examined why and in what ways Duhem was opposed to the dominant way of conducting science at the time, and how his opposition brought him to the famous Duhem problem and his ideas regarding the impossibility of crucial experiments in physics. Upon investigating the Duhem problem, I have analyzed that the problem consists of two parts, which I used Roger Ariew's naming of them, non-separability, and non-falsifiability.

I have claimed that the main focus of Duhem while introducing the Duhem problem was the non-separability part of the problem, and non-falsifiability emerges as a direct result of non-separability. That is why I thought it was important to examine Quine's contributions to the Duhem problem, since Quine's and Duhem's ideas are considered to be closely linked, and how the Duhem-Quine thesis differs from the original version of the problem that Duhem introduced. Then, I showed that the Duhem-Quine thesis also contains a hypothesis regarding the confirmation of theories, apart from non-separability and non-falsifiability.

The part regarding the confirmation of theories, which claims that any theory can be held true if some adjustments are made elsewhere in the system, is shown to be Quine's addition to the problem since Duhem had not had such a claim. Furthermore, it became clear to me while examining their solution that the problem tackled by Howson and Urbach was not the original problem Duhem proposed because it was in a structure that was expanded into the Duhem-Quine thesis. That was another reason why before examining the Bayesian solution in thesis, I believed it was important to investigate Quine's contributions to the Duhem problem.

Before moving to Bayes' theorem and the Bayesian solution, I introduced some axioms and theorems in probability calculus because I believe that they are crucial to understanding both Bayes' theorem and the Bayesian solution to the Duhem problem. With the help of the introduction of the related axioms and theorems, I have provided information regarding different versions of Bayes' theorem and explained what they mean and how they can be used. Showing the different versions of the theorem was important to tackle and explain the Bayesian solution to the Duhem problem because they are used throughout the solution.

As I have said earlier, the focus of Howson and Urbach is mainly the falsification and confirmation aspects of the Duhem problem. They do not explicitly state that they provide an answer to the non-separability aspect. They even say that they do not think theories are as entangled as they were claimed to be. However, upon investigating their solution, it became apparent to me that the solution they proposed also provides an answer to the non-separability aspect. In order for the Bayesian solution to be understood more clearly, I have used two examples that had both also been used by Howson and Urbach. With the ravens paradox example, the aim was to show that different kinds of evidence provides different degrees of confirmation and disconfirmation, which helps to show the solution's answer to the non-falsifiability aspect of the problem. With the atomic weight example, the aim was to demonstrate that even if the prior probabilities of hypotheses are changed, the outcome of the calculation of the posterior probabilities is not that different from the previous calculation. In addition, the usage of Bayes' theorem's different versions, (B1(i)) and (B2) in particular, in the calculations throughout the atomic weight example gave me insights that they can be used to give an answer to the non-separability aspect. That is why I claim that the Bayesian solution Howson and Urbach proposed provides a viable answer to both non-separability and non-falsifiability aspects of the Duhem problem.

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APPENDICES

A. TURKISH SUMMARY / TÜRKÇE ÖZET

Bu tezin amacı, Colin Howson ve Peter Urbach'ın Duhem Problemi'ne Bayesci çözümünün uygulanabilir olup olmadığını araştırmaktır. Esas olarak sorunun bir kısmına odaklansalar da, çözümlerinin uygulanabilir olduğunu iddia edeceğim. Bahsettiğim kısım yanlışlanamazlık (non-falsifiability) kısmı, problemin diğer kısmı ise çözümünün de geçerli olduğunu iddia ettiğim ayrılamazlık (non-separability) kısmı.

Tezin ilk bölümünde Pierre Duhem'in akademik kariyeri ve çalışmalarının tarihsel arka planı ve ardından Duhem Problemi'ni formüle etmesi ve çözümü hakkında bilgi veriyorum. Sonrasında Quine'ın Duhem Problemi ile ilgili düşüncelerini ve Quine'ın düşüncelerinin Duhem'inkinden nasıl farklılaştığını inceliyorum. Ardından Bayes'in Teoremi'ni anlamak için önemli olduğuna inandığım olasılık hesabındaki (probability calculus) bazı aksiyom ve teoremleri açıklayarak Bayesci olasılığa odaklanıyorum. İlgili aksiyom ve teoremleri açıkladıktan sonra, Bayes'in Teoremi'nin farklı versiyonları hakkında bilgi vererek, bunların ne anlama geldiği ve nasıl kullanılabileceği hakkında bazı fikirler veriyorum. Daha sonra Colin Howson ve Peter Urbach tarafından Bayesci bir çözüm olan Duhem Problemine önerilen çözüm incelenmekte ve Duhem problemine uygulanabilir bir çözüm olup olmadığı tartışılmaktadır. Bayesci çözüme yönelik bazı itirazlara atıfta bulunarak tezi sonlandırıyorum ve bunların nasıl ele alınabileceğine dair bazı düşünceler sunuyorum.

Duhem'in akademik kariyerini, bilim ve felsefe alanındaki çalışmalarını daha iyi anlamak için genel olarak Duhem'in hayatına ve o dönemde bilim ve akademik çevrelerde hakim olan görüşlere bir göz atmanın önemli olacağını düşündüm. Örneğin, Duhem dindar ve Katolik bir insan olarak yetiştirilmişti ve bu onun bilime ilgi duymasında kısmen rol oynamıştı çünkü bir Katolik okulundaki eğitimi boyunca Duhem fen bilgisi öğretmeninden çok etkilenmiş ve fizik okumak istemiştir. Dindar olmasının olumsuz yanları da olmuş olabilir; örneğin, Duhem ile Fransız akademi camiasının dindar şahsiyetlerin akademide yer alması fikrine karşı çıkan fikir ayrılıkları ve Fransız akademi camiasındaki bazı güçlü şahsiyetlerle kişisel münakaşaları gibi, ve bunlar, çalışmalarını ve o dönemde bilimi yürütmenin baskın yoluna neden itiraz ettiğini de etkileyen etmenler arasında yer almış olabilir.

O zamanlar bilimi yürütmenin baskın yolu, Newton Metodu veya tümevarım yöntemi (inductive method) olarak adlandırılan yöntemdi. Bu yöntem, fizikte deneysel gerçeklerden başka gerçeklerin olmadığını belirtir. Bu, bilimdeki teorilerin ampirik gözlemlerden elde edilen kanıtlara ve verilere dayandığı ve algılanamayan herhangi bir kavramın bir teorinin temeli olamayacağı anlamına gelir. Ancak Duhem, sadece ampirik gözlemlerle doğrudan algılayamayacağımız teorilerle tanımlanan bazı ölçümler veya araçlar kullanmamız gerektiğini savunuyor. Bu nedenle, gözlemsel unsurlar dışındaki tüm unsurların reddedilmesi düşüncesine karşı çıkıyor. Duhem'in bilimsel görüşü, ampirist ve metafizik görüşler arasında bir tür orta yoldur. Onun görüşü, gözlemlerle doğrudan algılanabilen ve algılanamayan unsurları içerir. Bu nedenle tümevarım yöntemine karşı çıkıyor ve tümevarım yöntemiyle ilgili birbiriyle ilişkili iki sorun olduğunu iddia ediyor. Bunlardan biri Duhem Problemi, ikincisi ise fizikte kritik deneylerin (crucial experiments) imkansızlığıdır.

Duhem Problemini, fizikte teorileri diğer teorilerden bağımsız kullanmayız ve kullanamayız diyerek açıklayabiliriz. Bir teoriyi kullanmak istediğimizde her zaman diğer teorilerden yardım alırız. Buna ayrılamazlık da denilebilir çünkü teoriler birbirinden ayrı olarak kullanılamaz. Duhem ayrıca bir hata veya beklemediğimiz bir gözlemle karşılaştığımızda ayrılamazlık nedeniyle sorunun tam olarak nerede olduğunu belirleyemeyeceğimizi belirtir. Buna yanlışlanamazlık adını verebiliriz çünkü hangi teorinin hataya neden olduğunu ve yanlışlanması gerektiğini belirleyemeyiz. Bu nedenle, yanlışlanamazlık, ayrılamazlığın doğrudan bir sonucu olarak ortaya çıkar.

Kritik deneyler söz konusu olduğunda, Duhem fizikte böyle bir deney olamayacağını belirtir. Bunun nedeni, kritik deney kavramının, bir deneyin, birbiriyle mücadele içinde olan teoriler arasındaki teorilerden birinin başarılı, diğerinin başarısız olduğunu kesin olarak göstermesi anlamına gelmesidir. Ancak fizikte bu, ayrılamazlık ve yanlışlanamazlık nedeniyle mümkün değildir. Kuramları ayrı ayrı değerlendiremeyeceğimiz için, bir kuramın yanlışlanabilirliğinden kesin olarak emin olamayız. Ayrıca bir deneyin kritik bir deney olabilmesi için tüm olasılıkların değerlendirilmesi gerekir. Demek istediğim, iki rakip teori dışında, her zaman bilim insanlarının henüz aşikar olmadığı üçüncü bir seçenek olabilir. Bu nedenle fizikte kritik deneyler mümkün değildir.

Duhem bu sorunlara bir cevap veriyor. Buna sağduyu (good sense) diyor. Bir bilim insanı sistemde ne tür değişiklikler yapacağına karar verdiğinde Duhem, rehberinin sağduyu olması gerektiğini söyler. Duhem'in sağduyu olarak adlandırdığı şey, mantığa göre yaptığımız seçimler değil, daha sezgisel bir akıl yürütme türüdür. Duhem, bilim insanının verdiği kararın kesin olarak doğru olmadığını kabul eder, ancak bilim insanı deneyin gereklerini yerine getirir ve hata ortadan kalkarsa sonuçtan memnun olabilir.

Quine'ın iki dogmayla ilgili teorisi, Duhem'in teorisiyle o kadar yakından bağlantılıdır ki, daha sonra teorilerinin bazı biçimleri birleştirildi ve Duhem-Quine tezi olarak adlandırıldı. Bu nedenle Quine'ın görüşünün Duhem Problemi'nden nasıl farklı olduğunu incelemenin önemli olduğuna inanıyorum. Quine, ifadeleri (statements) diğer ifadelerden ayrı değerlendiremeyeceğimiz konusunda Duhem ile aynı fikirdedir. Quine ayrıca, bir bilim alanının sınır koşullarının deneyimler (experience) olduğunu ve alanın sınır koşullarını oluşturan deneyimlerin, alanın içindeki ifadelerle bağlantılı olmadığını söyler. Yalnızca sistemi bir bütün olarak etkileyen bazı durumlarda, deneyim alanın iç kısmıyla ilişkilendirilebilir. Ancak bu, deneyde beklenmeyen bir sonuç ortaya çıktığında hiçbir şeyin değiştirilmemesi gerektiği anlamına gelmez. Ve alan, deneyim olan sınır koşulları tarafından tam olarak düzgün bir şekilde belirlenmediği için, hangi ifadelerin yeniden değerlendirilmesi gerektiği, yapılacak net bir seçim değildir. Bu nedenle Quine, hatanın nedeninin nerede olduğunun belirsizliği nedeniyle, bir teoriyi doğrulamak istiyorsak, bunu sistemin başka bir yerinde bazı ayarlamalar yaparak yapabileceğimizi iddia ediyor. Ona göre, bu herhangi bir teori için geçerli bir durumdur. Ve aynı nedenden dolayı, hiçbir teori revizyondan muaf değildir.

Quine'ın düşünceleri, sistemin herhangi bir yerinde gerekli ayarlamaları yaparsak herhangi bir teorinin doğru tutulabileceği fikriyle Duhem'in düşüncelerinden farklıdır. Duhem, bir teorinin bazı değişiklikler yaparak doğrulanması hakkında bir şey söylemez. Sadece hatanın nerede olduğunu bilemeyeceğimizi belirtir. Duhem Problemi'nin ayrılamazlık ve yanlışlanamazlık olmak üzere iki bölümden oluştuğunu söylediğimizde, Duhem-Quine tezinin de ek olarak teorilerin doğrulanmasına ilişkin bir ifade içerdiğini söyleyebiliriz. Duhem-Quine tezini iki kısma ayırırsak, bunlar: 1) hipotezler birbirinden ayrılamaz olduğundan, hiçbiri tek başına yanlışlanamaz ve 2) belirli bir hipotezi doğrulamak istiyorsak, bunu sistemin başka bir yerinde bazı ayarlamalar yaparak yapabiliriz. Görüldüğü gibi ikinci kısmın Duhem'in söyledikleriyle hiçbir ilgisi yoktur. Duhem, bir teorinin düzeltmelerle doğrulanması hakkında bir şey söylemez, sadece hatanın nerede olduğunun tespit edilemeyeceğini belirtir.

Olasılık Hesabı ile ilgili bazı bilgiler vermenin, Duhem Problemi'nin Bayesci çözümünü anlamak için gerekli olduğuna inanıyorum. Bazı kavramların burada ele alınması ve açıklanması gerekebilir. Bu noktada, h bir hipotezin gösterimi olsun ve e kanıtın gösterimi olsun. Öncel olasılık (prior probability), P(h), bir hipotezin kanıttan önceki olasılığı anlamına gelir. Sonsal olasılık (posterior probability), P(h / e), kanıtlar ışığında bir hipotezin olasılığını ifade eder. Bir hipotezin sonsal olasılığı, öncel olasılığından yüksekse, bu, kanıtların hipotezi desteklediği anlamına gelir. Bir hipotezin öncel olasılığı, sonsal olasılığından yüksekse, bu, kanıtların hipotezi doğrulamadığı anlamına gelir. Bayes teoremine göre, bir hipotezin sonsal olasılığı üç olasılığa bağlıdır; hipoteze bağlı kanıtın olasılığı, P(e / h), kanıtın öncel olasılığı, P(e) ve hipotezin öncel olasılığı, P(h). Teorem, h'nin sonsal olasılığının, hipoteze bağlı olarak kanıtın olasılığının h'nin öncel olasılığıyla çarpımının e'nin öncel olasılığına bölünmesine eşit olduğunu söyler: $P(h \mid e) = P(e \mid h)\, P(h) / P(e)$, burada P(h) ve P(e)

0'dan büyüktür. Bu, Bayes teoreminin bir versiyonudur, ancak diğer bazı versiyonları da tezde tanıtılıyor ve inceleniyor. Biz Bayes teoreminin yukarıda açıklanan versiyonuna (B1) diyelim.

Bayes teoreminin tezde bahsedilen diğer versiyonlarından da kısaca bahsetmek gerekirse, eğer (B1) içinde P(e) yerine $P(e \mid h)P(h) + P(e \mid {\sim}h)P({\sim}h)$ yazarsak, ki bunu yazmak için olasılık hesabı içindeki teoremlerden birini kullanıyoruz, ve bu yeni oluşturduğumuz versiyona da (B1(i)) dersek, teorem $P(h \mid e) = P(e \mid h) P(h) / (P(e \mid h)P(h) + P(e \mid {\sim}h)P({\sim}h))$ haline dönüşür. Bayes teoreminin ikinci formülasyonu da, ona da (B2) diyelim, $P(h_k \mid e) = P(e \mid h_k)P(h_k) / \Sigma^n_{i=1}P(e \mid h_i)P(h_i)$ şeklinde ifade edilebilir. Ve son olarak, Bayes teoreminin üçüncü formülasyonunu da, (B3) diyelim, $P(h \mid e) = P(h) / [P(h) + (P(e \mid {\sim}h) / P(e \mid h))P({\sim}h)]$ şeklinde gösterebiliriz. Burada (B2) (B1(i))'in daha genelleştirilmiş bir formülasyonu olarak görülebilir, ve (B3) de bize kanıt e'nin hipotez h'ye ve h'nin tersi ~h'ye bağlı olasılıklarına sahip olduğumuz durumlarda yardımcı olacaktır. Bayes teoreminden ve çeşitli versiyonlarından bahsettiğimize göre Howson ve Urbach'ın Duhem Problemi'ne sundukları çözümü incelemeye geçebiliriz.

Howson ve Urbach, grup olarak kullanılan teoriler yanlışlansa bile bireysel olasılıklarının değiştiğini belirtiyor. Bu değişiklikler Bayes teoremine atıfta bulunur ve Bayesci olasılık ile açıklanabilir. Duhem, teorileri diğer teorilerden ayrı değerlendiremeyeceğimizi, yani ayrılamazlığın olduğunu ifade etse de, Bayes olasılığı ışığında teorilerin bireysel olasılık değerlerine sahip olduğunu söyleyebiliriz. Bununla birlikte, her teorinin olasılık değeri, diğer teorilerden ayrı olarak ölçülmez çünkü diğer teorilerle birlikte veya bağlantılı olarak kullanılan teoriler, bu teorilerin olasılık değerlerini etkiler. Ancak, yine de, bireysel teorilerin olasılık değerlerini ölçebiliriz ve bu bize teorileri bireysel olarak değerlendirme olanağı konusunda bir avantaj sağlar. Daha sonra, teorilerin öncel ve sonsal olasılıklarını göz önünde bulundurarak, sistemdeki hangi teorinin değiştirilmesi veya terk edilmesi gerektiğine karar verebiliriz. Aldığımız karar, şüpheye yer bırakmayacak kadar doğru olmayabilir, ancak en olası hata nedeni olacaktır. Bunlara ek olarak, Howson ve Urbach'ın, çözümleri ayrılamazlığı da ele almasına rağmen, Duhem probleminin yanlışlanamazlık yönüne daha fazla odaklandıklarını da not etmeliyim.

Howson ve Urbach, Duhem Problemi'ne Bayesci çözümlerini açıklarken, çözümün bazı yönlerini açıklığa kavuşturmaya yardımcı olan iki örnek kullanırlar. Örneklerden ilki kuzgunlar paradoksu. Örnekler, farklı türde kanıtlarla karşılaşıldığında hipotezlerin farklı derecelerde doğrulanabileceğini veya yanlışlanabileceğini göstermek için kullanılır. Örneğin, ilk örnekteki "tüm kuzgunlar siyahtır" ifadesini kullanırsak, siyah olmayan ve kuzgun olmayan bir nesne görmek ile siyah bir kuzgun görmek her ikisi de ifadeyi doğrular diyebiliriz, ancak sağladıkları doğrulama dereceleri aynı değildir. Bu örnek, kanıtın bir hipotezi doğrulayabileceğini ve yanlışlayabileceğini ve farklı kanıt türlerinin hipotez için farklı derecelerde doğrulama sağlayabileceğini gösterdiği için Duhem Problemi'nin yanlışlanamazlık yönüne bir cevap sağlama yolunda çözüme yardımcı olması açısından önemlidir.

Ancak bir kez daha vurgulamak gerekir ki Bayesci epistemolojiye göre, iki farklı verinin bir hipotezi doğrulaması, onu eşit şekilde doğruladığı anlamına gelmez. Aralarında bir dereceye kadar doğrulama vardır. Kuzgunlar paradoksu durumunda, kuzgunlar paradoksuna Bayesci çözüm, bir hipotez ve kanıtla ilgili doğrulama dereceleri olduğunu gösterir. Siyah olmayan ve kuzgun olmayan bir nesne görmek, hipoteze siyah bir kuzgun bulmakla aynı derecede katkıda bulunmaz. Bu durumun neden böyle olduğunu da Bayesci olasılık ile gösterebiliriz.

Bayes teoreminin (B1) versiyonunu kullanırsak, ve B'yi siyah olma durumu ve R'yi kuzgun olma durumu için kullanırsak, elimizde iki farklı kanıt durumu için iki farklı denklem olur. Bu denklemler:

i) $P(h \mid RB) / P(h) = P(RB \mid h) / P(RB)$

ii) $P(h \mid {\sim}R{\sim}B) / P(h) = P({\sim}R{\sim}B \mid h) / P({\sim}R{\sim}B)$.

Bu denklemleri ve bazı olasılık aksiyomlarını kullanarak sadeleştirmeler yaptığımızda denklemler $P(h \mid RB) / P(h) = 1 / P(B \mid R)$, ve $P(h \mid {\sim}R{\sim}B) / P(h) = P({\sim}R \mid {\sim}B)$ şekline dönüşür. Bu noktada öncelikle ilk denkleme odaklandığımızda, eğer "tüm kuzgunlar siyahtır" ifadesinin öncel olasılığı yüksek bir değerse, siyah bir kuzgun görmek her ne kadar ifadenin sonsal olasılık değerini yükseltse de bu yükselme çok da yüksek olmaz. Öte yandan, eğer "tüm kuzgunlar siyahtır" ifadesinin öncel olasılığı o kadar da yüksek bir değere sahip değilse, diyelim ki doğru olma olasılığı yanlış olma olasılığından sadece biraz daha yüksekse, bu durumda siyah bir kuzgun görmek ifadenin sonsal olasılık değerini hatırı sayılır derecede yükseltir.

İkinci denkleme odaklandığımızda ise, yani siyah olmayan ve kuzgun olmayan bir nesne görmeyi kanıt olarak aldığımız denkleme odaklandığımızda, kuzgunların hiçbirinin siyah olmadığına ikna olsak bile, siyah olmayan sayısız şeyin olduğunu güvenle varsayabileceğimiz için, siyah olmayan şeyler kümesindeki kuzgunların sayısı önemli ölçüde küçük olacaktır. Yani siyah olmayan ve kuzgun olmayan bir şeyi gözlemleme olasılığı 1'e önemli ölçüde yakın olacaktır. Sonuç olarak, siyah olmayan ve kuzgun olmayan bir şeyi gözlemlemek h'nin olasılık değerinde önemli bir değişiklik yapmaz; h'nin sonsal ve öncel olasılıkları temelde aynı olacaktır; ve siyah olmayan ve kuzgun olmayan bir şey gözlemlemenin h'nin olasılığına sağladığı katkı da göz ardı edilebilecek derecede küçük olacaktır.

Elementlerin atom ağırlıklarıyla ilgili olan diğer örnek, ifadelerin öncel olasılıkları yeniden atansa bile sonucun büyük ölçüde değişmeyeceğini açıklamak için kullanılır. Örnek, farklı varsayımların öncel olasılıkları, her ikisinin de doğru olması yanlıştan daha olası olacak şekilde atandığında, olasılık değerleri farklıysa, sonsal olasılık değerlerinin son derece farklı olduğunu gösterir. Ek olarak, örnek, varsayımların öncel olasılık değerleri birbirlerine çok daha yakın atansa bile, sonsal olasılık değerlerinin yine de önemli ölçüde farklı olacağını göstermektedir. Bu nedenle, doğru olma olasılığı yanlıştan daha yüksek olmasına rağmen, ifadenin yanlış olma olasılığı oldukça yüksekse, olasılıklar yeniden atandıktan sonra bile ifadenin yanlış olma olasılığının yüksek olduğunu söyleyebiliriz. Aynı şey, bir önermenin doğru olduğu senaryo için de geçerlidir.

Howson ve Urbach tarafından sunulan atomik ağırlık örneği olarak adlandırılabilecek diğer örnek, Duhem problemine çözümlerini göstermek için kullandıkları ana örnektir. Bunun nedeni anlaşılabilir, çünkü hem hangi teorinin terk edilmesi gerektiği sorusuna cevap verebilecek bir çözüm sunuyor, hem de öncel olasılıklar hakkında ortaya çıkabilecek bazı itirazlara cevap veriyor. Bunların yanı sıra teorileri tek tek ya da diğer teorilerle birlikte değerlendirme konusunda da yardımcı olduğunu düşünüyorum.

Atom ağırlığı örneği, kanıtlarla yanlışlanan veya çürütülen farklı hipotezlerin çok farklı derecelerde yanlışlanabileceğini veya çürütülebileceğini göstermek için Duhem Problemi'ne Bayesci çözümle ilgili olarak Howson ve Urbach tarafından verilmiştir. Örnek, bir elementin atom ağırlığına ilişkin bazı hesaplamalarla ilgilidir. Örnek, William Prout'un tüm maddenin bir temel elementin farklı kombinasyonlarından oluştuğu fikrini kullanır, Prout için bu hidrojendi; ve bu nedenle Prout, tüm elementlerin atom ağırlığının, hidrojenin atom ağırlığının tam sayı katları olduğuna dair başka bir fikir öne sürdü. Aklını çelen bazı delillerle karşılaşınca, örneğin klor elementinin atom ağırlığını 35,83 olarak hesapladığında, hidrojen fikrinden vazgeçmek yerine, klorun atom ağırlığı değerini en yakın tam sayı olan 36 olarak değiştirmiştir. Benzer şekilde Thomas Thomson da hidrojenin atom ağırlığını 0,125 olarak hesaplamış ve bor elementinin atom ağırlığını 0,829 olarak gösteren gözlemsel verilerle karşılaşınca hidrojenin atom ağırlığının katı olması için değeri 0,875 olarak değiştirmiştir. Prout ve Thomson'ın davranışları, bilim insanının kendisini çürüten bir kanıtla karşılaştığında tüm düşünce sisteminden vazgeçmeyeceğini göstermektedir. Bilim insanı, hatayı ortadan kaldırmak için verileri sisteme göre ayarlamayı veya sistem içinde temel bir hipotez olmayan ve terk edilmesi daha kolay olan bir hipotez bulmaya çalışmayı tercih edecektir.

Bayesci olasılık, Prout ve Thomson'ın yanlışlayan kanıtlarla karşılaştıklarında fikirlerinden vazgeçmemekte haklı olup olmadıklarını anlamamıza yardımcı olabilir. Prout'un hipotezi, ölçüm tekniklerinin ve kullanılan kimyasalların saflığının doğru olduğu gibi uygun bir varsayımın birleşimiyle, klor elementinin atom ağırlığını 35,83 olarak gösteren kanıtlarla karşılaşıyor diyelim. Kanıtın hipotez ve varsayımın kombinasyonu ile uyumlu olamayacağı görülebilir, çünkü kanıtlar hipotezi veya varsayımı veya her ikisini de doğrulamaz. Onay değerlerinin nasıl değiştiğini ve hangilerinin yeniden değerlendirilmesi veya değiştirilmesi gerektiğini belirlemek için Bayes olasılığını kullanabiliriz. Burada t Prout'un hipotezine, a uygun varsayıma ve e kanıta atıfta bulunsun. Ayrıca, P(t) t'nin öncel olasılığını ifade etsin, P(a) a'nın öncel olasılığını belirtsin, P(e) e'nin olasılığını belirtsin, P(t | e) t'nin e ışığında sonsal olasılığını ifade etsin, P(a | e) verilen bir e ışığında a'nın sonsal olasılığını ifade etsin, P(e | t) t ışığında e'nin olasılığını (likelihood) ifade etsin, ve P(e | a), verilen a ışığında e'nin olasılığını ifade etsin. Bu durumda, (B1) kullanarak şunu yazabiliriz:

t için) $P(t \mid e) = P(e \mid t)P(t) / P(e)$,

a için) $P(a \mid e) = P(e \mid a)P(a) / P(e)$.

Şimdi t ve a'nın öncel olasılıklarını belirleyerek başlayalım. Howson ve Urbach, Prout'un hipotezinin birçok bilim insanı tarafından doğru kabul edildiğini ve doğruluğuna olan güvenin son derece yüksek olduğunu belirtiyor. Bu nedenle, t'nin öncel olasılığını oldukça yüksek bir değer olarak, örneğin 0,9 olarak tahmin edebiliriz. Kullanılan aletler veya kimyasallarla ilgili uygun varsayım için ise güven, Prout'un hipotezi kadar yüksek değildi. Bunun nedeni, ağırlığı ölçmek için kullanılan aletlerin hata payının yüksek olması ve kimyasalların saflığının bazen sorgulanabilir olmasıdır. Atom ağırlığı ölçümlerinin her zaman aynı sonuçları vermemesinin nedeni budur. Bu nedenle, t ve a arasında önemli bir güven derecesi olduğundan, a'nın öncel olasılığının 0,9'dan oldukça küçük bir tahminini yapmalıyız. Ancak a'da belirtilen alet ve kimyasallar hala kullanıldığı için, a'nın öncel olasılığının 0,5'ten büyük olması gerekir ve bu demektir ki a'nın doğru olma olasılığı, yanlış olma olasılığından daha yüksek olmalıdır. Öyleyse, a'nın öncel olasılığının 0,6 olduğunu varsayalım.

Yukarıda t ve a'nin sonsal olasılık değerlerini hesaplamak için (B1) kullanarak oluşturduğumuz denklemlerde (B1(i)) kullanarak bazı değişiklikler yaptığımızda görürüz ki P(e) yerine $P(e \mid t)P(t) + P(e \mid {\sim}t)P({\sim}t)$, ve $P(e \mid t)$ yerine $P(e \mid t \wedge a)P(a \mid t) + P(e \mid t \wedge {\sim}a)P({\sim}a \mid t)$ yazabiliriz. Buna ek olarak, $P(a \mid t)$ yerine $P(a)$, ve $P({\sim}a \mid t)$ yerine $P({\sim}a)$ yazabiliriz çünkü kullanılan aletlerin doğruluğunun değeri ve kimyasalların saflığı Prout'un hipotezinin değeriyle alakalı değildir; bunlar birbirlerinden bağımsız durumlardır.

Bu noktada, $P(t \mid e)$, yani t'nin sonsal olasılığının 0,878'e ve $P(a \mid e)$, yani a'nın sonsal olasılığının 0,073'e eşit olduğu hesaplanabilir. Öncel olasılıklarının sırasıyla 0,9 ve 0,6 olduğunu unutmayalım. Dolayısıyla, varsayımın olasılığı büyük ölçüde değişirken, hipotezin olasılığındaki değişiklik oldukça küçük olduğundan, kanıtların hipotez ve varsayım üzerindeki yanlışlama etkilerinin önemli ölçüde farklı olduğu görülebilir. Bu nedenle, atom ağırlığı örneği, hipoteze kıyasla bir varsayımın ne derece geçerli olduğunu hesaplayabileceğimizi göstermektedir. Ayrıca, Bayesci olasılığı kullanarak, teorinin hangi bölümünün hataya neden olma olasılığının daha yüksek olduğunu ve yeniden ayarlanması veya değiştirilmesi gerektiğini belirleyebileceğimizi söyleyebiliriz.

Bazı öncel olasılıkların seçildiği ve bunların kesin olmadığı söylenebilir, ancak Howson ve Urbach, öncel olasılıklara başka değerler atamamızın önemli olmayacağını gösteriyor. Bunu da hesaplamaların benzer sonuçlar göstermesinden görebiliriz. Örneğin, t hipotezinin öncel olasılığı 0,7 olursa ve diğer değerler değişmezse, hipotezin sonsal olasılığı P(t | e), 0,65'e eşit olur, ve a'nın sonsal olasılığı P(a | e), 0,21'e eşit olur. Bu nedenle, yanlışlayıcı kanıtlar ışığında hipotezin doğru olma olasılığının yanlıştan daha yüksek olduğu ve yardımcı varsayımların yanlış olma olasılığının doğru olmaktan çok daha yüksek olduğu sonucuna varılabilir. Bu nedenle, öncel olasılıkların değerlerini yeniden atasak bile sonuçlar büyük ölçüde değişmez diyebiliriz.

Howson ve Urbach tarafından Duhem Problemi'ne önerilen Bayesci çözümün geçerli bir çözüm olduğuna inanıyorum. Yine de Howson ve Urbach, bunu Duhem Problemi olarak ele alsalar da, başlangıçta odaklandıkları problem daha çok Duhem-Quine tezi veya en azından Duhem probleminin bir parçası gibi görünüyor, çünkü esas olarak yanlışlama ve doğrulamaya odaklanıyorlar. Ancak, çözümlerinin orijinal Duhem Problemi'ne de uygulanabilir bir çözüm sunduğunu söyleyebiliriz. Demek istediğim, Duhem'in ortaya koyduğu ve sorunun temelini oluşturduğu ayrılamazlığa bir çözüm sunuyor diyebiliriz. Başka bir deyişle, Howson ve Urbach'ın Bayesci çözümü, Duhem Problemi'nin hem ayrılamazlık hem de yanlışlanamazlık yönlerine bir çözüm sunmaktadır.

Bayesci olasılıl hem ayrılamazlık hem de yanlışlanamazlık için bir çözüm sunuyor çünkü bence teorileri bireysel olarak değerlendirmemize izin veriyor. Bu değerlendirme teorilerin bireysel olasılık değerleridir. Teorilerin olasılık değerleri her zaman diğer teorilerden bağımsız değildir, ancak diğer teorilerin etkisi dikkate alınarak hesaplanabilir. Bu hesaplamanın mümkün olduğunu da hem atom ağırlığı örneğinde, hem de Bayes teoreminin özellikle (B1(i)) ve (B2) formülasyonlarında görebiliyoruz. Bu şekilde, ayrılamazlık problemini çözmek için bir aracımız olmuş olur Bayesci olasılık sayesinde. Teorileri birbirinden ayrı, ayrı ayrı değerlendiremediğimiz durumlarda ise birbirleriyle olan ilişkileriyle birlikte değerlendirme şansı, Bayesci olasılığın bize sunduğu araçtır. Yanlışlanamazlık konusunda ise, kanıtların farklı derecelerde doğrulama veya yanlışlama sağlaması, teorilerin farklı derecelerde etkilenmesi ve örneklerde gösterildiği gibi teorilerin farklı derecelerde etkilendiğinin tespit edilebilmesi, yanlışlanamazlığın geçerli bir Bayesci çözüme sahip olduğunun göstergeleridir.

Howson ve Urbach'ın Duhem Problemi'ne çözüm olarak ortaya attığı Bayesci çözüme karşı sunulan itirazlar iki temel noktada ele alınabilir. Bunlardan birisi Bayesci çözümün Duhem Problemi'nin ayrılamazlık yönüne bir çözüm sunamıyor olduğu iddiasıdır. Bu iddiaya göre bazı olasılık hesaplamalarında kullanılan bir tür bağımsızlık varsayımı (independence assumption) Duhem'in ortaya attığı problemin ayrılamazlık yönüne uygun olmayan bir durum. Bu itirazlara cevap verirken kullanılan bağımsızlık varsayımının bazı durumlarda kullanılan teorilerin olasılık değerlerinin birbirlerini etkilemediğini göstermek için kullanıldığını, kullanılmasının gerekli olmadığını ve kullanılmadığı durumda da hesaplamaların aynı çıkacağını, ve bu bağımsızlık varsayımının hesaplamaları biraz daha kolay hale getirmek amacıyla kullanıldığını söylemek gerekir. Ayrıca, bağımsızlık varsayımı kullanılmadığı durumlarda da teorilerin olasılık değerlerinin birbirlerine bağlı olarak nasıl değişime uğradığını atom ağırlığı örneğiyle görmemiz mümkün. Atom ağırlığı örneğine ek olarak, teorilerin birbirleriyle bağlantılarının olasılık değerlerini nasıl etkilediğini, ve bu şekilde de ayrılamazlık sorununun çözülebileceğini, Bayes teoreminin (B1(i)) ve (B2) formülasyonlarını kullanarak da görmemiz mümkün.

Duhem Problemi'ne karşı sunulan Bayesci çözüme yapılan itirazlardan bir diğeri de öncel olasılık değerlerinin belirlenmesi konusundaki endişelere odaklanıyor. Bu konuda itiraz edenler diyorlar ki öncel olasılık değerlerinin belirlenmesi hususu kesinlik barındırmayan bir durum, ve bu yüzden de ortaya çıkan sonuçlar şüpheli olur. Yani bir başka deyişle, öncel olasılık değerleri kesinlik barındırmadığı için hesaplamalar da bize güvenilir sonuçlar sunamazlar. Ancak bunun tam olarak böyle olmadığını atom ağırlığı örneğinde net bir şekilde görüyoruz. Atom ağırlığı örneği bize gösteriyor ki öncel olasılık değerleri farklı bir şekilde belirlense bile, ortaya çıkan sonuçlar benzer olacaktır. Yani ilk durumda belirlediğimiz olasılık değerleri ve hesapladığımız sonsal olasılıklar, öncel olasılık değerlerinin daha farklı belirlendiği durumda da ilkine yakın sonuçlar verecektir. İlk durumda yanlış olma olasılığı çok daha yüksek olan hipotez, ikinci durumda yine yanlış olma olasılığı daha yüksek olan hipotez olacaktır. Sonuç olarak, öncel olasılık değerlerinin kesinlik barındırmadığına dair yapılan itirazlar, öncel olasılık değerlerinin farklı belirlendiği durumlarda da sonuçların benzer olduğunun gösterilmesiyle birlikte cevaplanabilecektir.

Özetlemek gerekirse, bu tezin amacı, Colin Howson ve Peter Urbach tarafından Duhem Problemi'ne önerilen Bayesci çözümü araştırmak ve çözümün uygulanabilir olup olmadığını göstermektir. Bu yolda Duhem'in ortaya attığı problemin iki yönü olduğunu, bunların da ayrılamazlık ve yanlışlanamazlık olduğunu gösterdim. Quine'in iki dogmaya dair ortaya attığı bazı görüşlerinin Duhem Problemi ile bağlantılı olduğunu düşündüğüm için Duhem-Quine tezi olarak da adlandırılan tezin Duhem'in görüşlerine ek olarak teorilerin doğrulanabilirliğine dair de fikirler barındırdığını göstermek istedim. Bunu yapmamın sebebi de Howson ve Urbach'ın ortaya attıkları çözümün de bir noktada odak noktasının doğrulanabilirlik ve yanlışlanabilirlik olmasıydı. Ancak durum böyle olsa da, Howson ve Urbach'ın ortaya attığı Bayesci çözümün Duhem Problemi'nin ayrılamazlık ve yanlışlanamazlık yönlerinin her ikisine de çözüm sağlayabildiğini belirttim. Bunun sebebi olarak da kuzgun paradoksu örneğinde de görüldüğü gibi teorilerin farklı çeşit kanıtlar ışığında farklı derecede doğrulanma ya yanlışlanma değerleri alabileceğinin, ve atom ağırlığı örneğinde ve Bayes teoreminin (B1(i)) ve (B2) formülasyonlarında da görülebileceği gibi teorilerin olasılık değerlerinin birbirleriyle bağlantılı olarak nasıl değişebileceğinin hesaplanmasının mümkün olduğunun gösterilebileceğini ortaya koydum. Ve sonuç olarak, Howson ve Urbach'ın Duhem Problemi'ne çözüm olarak sunduğu Bayesci çözümün uygulanabilir olduğunu ve problemin her iki yönüne de makul bir çözüm sunduğunu göstermiş oldum.

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