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Parsimony and Quantum Mechanics: An Analysis of the Copenhagen and Bohmian Interpretations

A Thesis Presented

by

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To the Keck Science Department
Of Claremont McKenna, Pitzer, and Scripps Colleges
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Parsimony and Quantum Mechanics: An Analysis of the Copenhagen and Bohmian Interpretations

By Jhenna Voorhis

Abstract: *Parsimony, sometime referred to as simplicity, is an effective criterion of theory choice in the case of Quantum Mechanics. The Copenhagen and Bohmian interpretations are rival theories, with the Bohmian interpretation being more parsimonious. More parsimonious theories have a higher probability of being true than less parsimonious rivals. The Bohmian interpretation should thus be preferred on these grounds.*

Introduction

Quantum Mechanics, the response to the discovery of the wave-particle duality of matter on the scale of sub-atomic particles, presents a sharp departure from classical physics. Probabilities replace definite values, and the nature of the world becomes a puzzle of superpositions and quantum potentials. There exist quite a few interpretations of Quantum Mechanics (Baggott 159), but two commonly referred to interpretations are the Copenhagen and Bohmian interpretations. The Copenhagen and Bohmian interpretations explain all the relevant phenomena that have been observed to date, making the two interpretations equally supported by the evidence (Albert 134; Baggott 157; Bohm *A Suggested Interpretation* 370; Allori and Zanghì 1747; Bell 111). Hence if we are going to prefer one of these theories to the other we must find some other grounds upon which to do so. Parsimony, sometimes referred to as simplicity, has long been debated as a criterion for theory choice[1] (McAllister; Sober; Quine). In this thesis I first argue that, other things being equal, the more parsimonious interpretation should be

1 We need not settle the issue of if Copenhagen and Bohmian Mechanics are different theories or interpretations of the same theory. We simply need to agree that any criteria we use for selecting and preferring theories also applies to interpretations.

preferred. I argue for this on the grounds that the more parsimonious interpretation has a higher probability of being true. Finally, I argue that the Bohmian interpretation is more parsimonious, and thus should be preferred.

In Section One I present and defend my version of 'parsimony'. I make two separate distinctions in my version of parsimony. First, I distinguish ontological parsimony from dynamic parsimony. The former concerns the number of (types of) entities posited by a theory, while the later concerns the number of (types of) events a theory posits. Second, I distinguish quantitative parsimony from qualitative parsimony. The former concerns the number of entities/events posited by a theory, while the later concerns the number of *types* of entities/events posited by a theory. I proceed to argue that the more parsimonious theory has a higher probability of being true, and should be preferred on these grounds.

In Section Two I analyze the Copenhagen and Bohmian interpretations of Quantum Mechanics. I measuring their relative parsimony levels by examining their respective explanations of the famous 'double-slit' experiment. I conclude the Bohmian interpretation should be preferred over the Copenhagen on the grounds of being more parsimonious, and thus more probable.

Before proceeding to my argument, as outlined above, it does well to introduce the double-slit experiment and the two interpretations of Quantum Mechanics under discussion. The traditional double-slit experiment consists of a photon source, S, placed in front of a double slit apparatus, consisting of a screen with two slits A and B, behind which is a photographic plate, P (Figure 1). When a photon is emitted from S towards the slits, it travels through the double-slit apparatus and registers on the photographic plate.

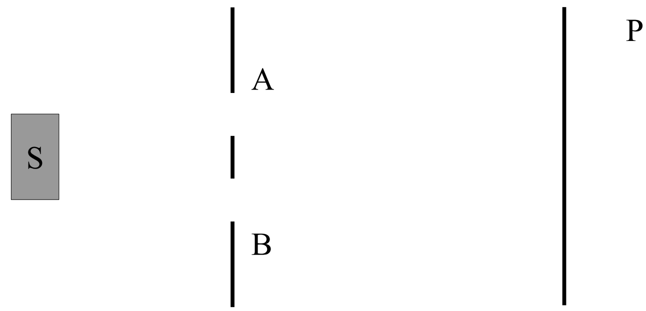

Figure 1: The set-up of the traditional double-slit experiment.

Should the photographic plate display distinct spots, it can be inferred that particles have struck the plate (Figure 2). Should the photographic plate display a continuous interference pattern, it can be inferred that waves have struck the plate (Figure 3). These results would be in line with the observed results of analogous experiments on the classical scale.[2] It would thus seem a simple matter of running the experiment and looking at the photographic plate to determine if photons behave like waves or particles.

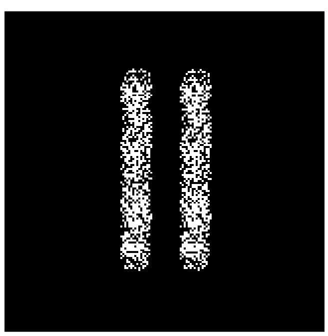

Figure 2: Distinct spots show where particles have struck the photographic plate, producing the expected pattern if photons in the double-slit experiment behave like particles.

Figure 3: A continuous interference pattern on the photographic plate that would be expected if photons in the double-slit experiment behave like waves.

2 The particle interpretation is analogous to shooting paintballs at a wall through two slats in a board. One expects to see two columns of paint on the wall, with distinct marks from each paintball fired. The wave interpretation is analogous to a similar experiment that uses a wave of water incident on a double-slit apparatus to produce the expected wave interference pattern.

The results of the experiment, however, make it difficult to classify the behavior of the photons as strictly particle-like or wave-like. Running the experiment, one finds that distinct spots form on the photographic plate, along with an interference pattern (Fig 4).

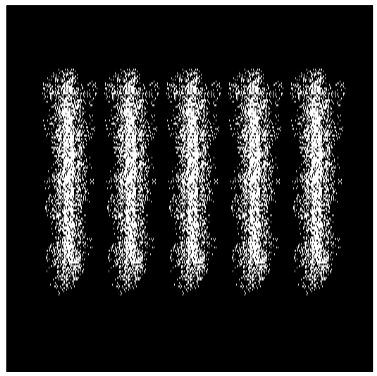

Figure 4: The photographic plate after running the double-slit experiment.

From the distinct spots on the photographic plate, it can be inferred that the photons striking the plate have particle-like behavior. However, from the interference pattern it can be inferred that photons have wave-like behavior. One might suppose that perhaps the photons emitted from S are colliding in a particle-like way with each other to produce this pattern. The experiment can be repeated ensuring only one photon is emitted at a time, eliminating the chance of photons colliding with each other. After a large number of photons have been emitted, the interference pattern emerges yet again. Additionally, similar results are obtained if electrons are used in place of photons.

This imparts both particle-like and wave-like properties to the photons, as they appear to be interfering with themselves as they pass through both slits simultaneously (wave-like behavior), and yet they strike the photographic plate at a specific point (particle-like behavior). Photons behaving like particles and waves presents a contradiction that classical mechanics cannot explain. “The classical physicist is mystified by this result, thinking that surely a single [photon] passes through one slit *or* the other, and thus cannot understand how a *particle* like the [photon] can 'interfere' with itself” (Townsend, 165). Quantum Mechanics answers the call for an account of the bizarre results of this experiment. I now present the Copenhagen and Bohmian interpretations of Quantum Mechanics.

The Copenhagen interpretation of Quantum Mechanics was originally devised by Niels Bohr and Werner Heisenberg. The Copenhagen interpretation has experienced some modifications since its initial construction, and I focus on the modern approach[3]. Now for some terminology that will be useful in explaining the Copenhagen interpretation. *State vectors* represent physical situations or states of affairs. A compilation of possible states vectors for a system (that is, the compilation of all the possible physical states of affairs for a particular system) comprises the *quantum state* of a system. The quantum state of a system is reflected through its *wave function*. Thus, a system is completely described by its wave function, and, additionally, evolves according to Schrödinger's equation.[4] The

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3 Townsend's books explore the modern interpretation quite extensively, refer to his works for further exploration and a mathematical grounding.

4 Schrödinger's equation can be represented in many forms, but for the Copenhagen interpretation I am referring to the following representation from Townsend:

$$i\hbar \frac{d}{dt}\left|\psi(t)\right\rangle = \hat{H}\left|\psi(t)\right\rangle$$

where $\hat{H}$ is the Hamiltonian Operator:

$$\hat{H} = \frac{\hbar^2}{2m}\nabla^2 + U$$

with *U* as potential energy, and $\psi(t)$ ket is the time-dependent wave function:

$$\left|\psi(t)\right\rangle = e^{-i\hat{H}t/\hbar}\left|\psi(0)\right\rangle$$

with $\psi(0)$ ket as the initial quantum state of the system (Townsend 94-5).

measurable properties of a system, such as position and momentum, are referred to as *observables*.

The Copenhagen interpretation stems from three basic postulates. Postulate 1 is that the state of a quantum mechanical system is completely described by the wave function (Baggott 43). Postulate 2 is that observable quantities are represented by mathematical operators, chosen to be consistent with the position-momentum commutation relation[5] (Baggott 44). Postulate 3 is that the mean value of an observable is equal to the expectation value of its corresponding operator (Baggott 45). This final postulate essentially tells one how to use the wave functions and operators to calculate the value of an observable.

These three, rather opaque, postulates can be recast as saying that particles exist in quantum states, described by their wave functions, with certain measurable properties. Using position as an example, all the possible outcomes of measuring the position of a particle are represented in its wave function, and assigned a probability amplitude. Before measurement, the particle is in a *superposition* of states, and it assigns a probability to all of its possible states. Upon actually measuring the position of a particle, the particle's wave function collapses to reflect the obtained result. This collapse entails the probability for finding the particle in the state it was actually found in going to 1, and the probabilities for all other possible states going to zero. To demonstrate, take a particle and

5 The position-momentum commutation relation is commonly known as the 'uncertainty principle' and claims the commutation of position and momentum operator will be non-zero. More specifically $[x, \hat{p}_x] = i\hbar$ which means that one cannot simultaneously, and with absolute precision, know the position and momentum for a quantum object.

before measurement the particle is in a superposition of states A, B, and C which correlate to specific positions. Each state is assigned a probability, less than one, that the particle is in the corresponding position. After measurement, the particle is found in state B. This leads to a collapse of the wave function, such that *P(B)* = 1 while *P(A)* = *P(C)* = 0. Such is the nature of the collapse of a wave function for the Copenhagen interpretation. It is a peculiar occurrence without precedence in classical mechanics.

It is key to note the superposition of states in the Copenhagen interpretation, as it is from this superposition that the particle is said to interfere with itself and produce the interference pattern observed in the double-slit experiment (Townsend 165). The wave function can be seen to change upon measurement of an observable under the Copenhagen interpretation. No such change from observation is posited under the Bohmian interpretation.

The Bohmian interpretation was first explored by Louis deBroglie, later resuscitated by David Bohm and supported by John Bell.[6] The Bohmian interpretation of Quantum Mechanics is based on two basic premises. Premise 1 is that particles exist with definite positions (Bell 162). Premise 2 is that the wave function serves to guide these particles, which evolves according to Schrödinger's equation[7] (Allori and Zanghi 1744-5; Cushing et al 236). "We then have a deterministic system in which everything is fixed by

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6 The works of Bohm and Bell are good references for further exploration of Bohmian Mechanics and provide the mathematical grounding that I am foregoing.

7 For the Bohmian interpretation, take Schrödinger's equation as being expressed in the form:

$$i\hbar\frac{\partial\psi}{\partial t}=\frac{-\hbar^2}{2m}\nabla^2\psi+V\psi$$

where ψ is the wave function, and *V* is the classical potential (Bohm *The Undivided Universe*, 28).

the initial values of the wave [function] and the particle configuration." (Bell 128) This deterministic characteristic of the Bohmian interpretation Quantum Mechanics sets it apart from the Copenhagen interpretation, which is indeterminate.[8]

It should also be noted that the wave function here represents more of a 'field' than a 'wave' and I will use the term *quantum field* as interchangeable with wave function. The quantum field is in a manner analogous to an electromagnetic field, and "just as the electromagnetic field obeys Maxwell's equations, the [wave function] field obeys Schroedinger's equation" (Bohm *A Suggested Interpretation* 373).[9] When combined with Schrödinger's equation this quantum field will produce the quantum potential, *Q*, which actually exerts the force on the particle to guide it.[10]

Bohm's quantum potential does not diminish with distance, being purely dependent on the form of the wave function. In this way, Bohmian Mechanics is a non-local hidden variable theory. 'Non-local' in that its wave field is a non-local variable, present and potent at any point in space while also a reflection of the state of all space. 'Hidden' in that the position of particles are not known, and thus hidden, although they do

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8 'Deterministic' is referring to causal determinism, where the world is seen as being the outcome of prior states. A particle's motion is the outcome of knowing all the initial conditions of the particle and the forces acting upon the particle. Indeterminism is thus the notion that the world is not the outcome of prior states, for whatever reason. The Copenhagen interpretation's indeterminism stems from not being able to *know* the initial conditions or forces with certainty, such a thing is simply *impossible*.

9 In polar form the general form of the wave function can be written as:

$$\psi = R\, e^{(iS/\hbar)}$$

where R is the amplitude and S is a phase factor (Bohm *The Undivided Universe*, 28).

10 Using the general form of the wave function, Q is:

$$Q = \frac{-\hbar^2}{2m} \frac{\nabla^2 R}{R}$$

where R is the amplitude of the wave function (Bohm *The Undivided Universe*, 28).

exist.[11]

The Bohmian interpretation can then be summarized as claiming that particles exist with definite positions in space and are influenced by their quantum fields, which are inseparable from the particles, characterized by their wave functions. This quantum field changes continuously and is causally determined, satisfying Schrödinger's equation (Bohm *The Undivided Universe* 29). A particle can thus be thought of as a ship on autopilot being guided by radio waves. The radio waves act as the quantum field, and have the effect of guiding the ship (Bohm *The Undivided Universe* 31-32).

The Copenhagen and Bohmian interpretations present an indeterminate and a determinate interpretation of quantum mechanics, respectively, and differ greatly on their explanations of quantum phenomena. Now that the basic tenants of each theory have been explored, it is time to examine parsimony as a means of choosing between the two interpretations.

11 Alternatively, it can also be considered a hidden variable theory in that it attempts to complete the Copenhagen interpretation by claiming that particles have definite positions at all times. This view is in line with the traditional connotation of hidden variable theories attempting to find that missing link which could transform the indeterminate Copenhagen interpretation into a determinate one.

Section One: Parsimony and Probability

It is my aim in this section to argue that the more parsimonious of competing scientific theories should be preferred. The more parsimonious theory will have a higher probability after the discovery of new evidence, for which both theories account.

An important definition to make clear is exactly what I mean by 'parsimony.' I focus on ontological and dynamic parsimony. In general, ontological parsimony claims that theories which entail the existence of fewer entities, or kinds of entities, are better than theories which entail the existence of more entities, or kinds of entities, other things being equal (Huemer 216). Dynamic parsimony, on the other hand, makes a similar claim but about the number and types of *events* an entity experiences. Parsimony is further separable into quantitative and qualitative parsimony. Qualitative parsimony is concerned with types of entities/events, and quantitative parsimony is concerned with the total number of entities/events (Nolan 330). As an example, qualitative parsimony would be concerned with the number of different elements (each different element is a different type of entity) which make up the water molecule, while quantitative parsimony would be concerned with the total number of atoms of each of those elements present (each atom is a specific entity of a certain type).

Throughout my argument, the term 'parsimony' refers to the overall parsimony of a theory. The overall parsimony is found through summing the number of entities/events which a theory postulates. To be clear, a more parsimonious theory posits fewer entities/events than a less parsimonious rival theory.

This interpretation of parsimony, however, naturally leads to the issue of deciding what constitutes an 'entity,' and what constitutes an 'event.' Following the work of E. C. Barnes, I take 'entities' to be constituted by physical things with distinct and independent existences, for example specific light waves (Barnes 354). The parsimony of such entities is the ontological parsimony of a theory. Additionally, I consider events involving those entities as contributing to a theory's parsimony, comprising a theory's dynamic parsimony. An event consists in a change in an entity's properties, excepting changes in time and, for the purposes of this paper, position.[12]

Each entity/event additionally belongs to a 'type.' These 'types' describe the properties of the entities/events which can be posited under the examined theory. As a simple example let's adopt a 'type of entity' which describes shmoranges. That is to say the entities posited from this description are of 'type shmorange' and share the property of *being* a shmorange, whatever that should mean. For the purpose of this demonstration, let us suppose we know the defining characteristics which all shmoranges share. A thing of type shmorange has the properties of being a physical thing with mass, a roughly round shape, and which is orange in color and edible. Following from this, any specific shmorange we posit will have these properties, since it is of type shmorange. Although my view of parsimony makes no appeal to 'types' it is instructive to make the qualitative/quantitative distinction in order to clarify the bounds of my claim. In

12 The condition regarding time prevents changes in time from being considered an 'event.' An entity existing at 1AM and then continuing to exist at 2AM does not constitute a dynamic change, and so is not considered an event. The condition regarding position prevents an entity's moving through space being considered an event. Note: this condition only applies to changes in position, but not to momentum, velocity or any other position dependent property of an entity.

summary, the term 'entity' refers to a specific physical thing, while 'event' refers to changes which entities experience. Now that those terms have been clarified, I return to the argument from overall parsimony.

In general, less parsimonious theories fit a wider range of possible evidence than their more parsimonious competitors. That is to say, theories with a higher total number of posited entities and events are capable of explaining a larger pool of possible evidence. As a demonstration, let's consider an shmorange on a table. The shmorange is of an arbitrary size, for ease take the shmorange to be 'size 1.' Take Theory A to posits that shmoranges are found as one object of size 1, while Theory B posits that shmoranges are found as compilations of sub-objects, each of size ¼. Both theories can be used to explain the observed phenomena of there being one shmorange on a table. Theory B, however, does so by positing the existence of more entities than Theory A, since four of the sub-objects would be necessary to explain there being a size 1 shmorange on the table. Additionally, while Theory B can explain the existence of one shmorange on a table, it can also be used to describe the existence of a size ¾ shmorange on the table, or any other shmorange whose size is a multiple of ¼.

This is an example of a less parsimonious theory, Theory B, fitting a wider range of possible evidence, namely accounting for any shmorange of a size that is a multiple of ¼. While most cases of competing scientific theories have this characteristic, of less parsimonious theories fitting a wider range of possible evidence, I do not stand to claim that all cases of competing scientific theories must have this characteristic. Without having any reason to believe that the case I present in Section Two, involving the Copenhagen and Bohmian interpretations, lacks this characteristic, I apply my argument to it in good conscience.

Later in my argument I discuss more parsimonious theories, paired with their evidence, having greater 'likelihoods' than less parsimonious theories, when paired with their evidence. In order to understand such a claim about 'likelihood,' or later a claim about 'prior probability,' a quick look at Bayesianism is necessary. Bayes' Theorem is, in itself, a mathematical derivation of probability calculus, which shows that for a proposition 'p,' given 'q,' the following relations hold:

$$P(p|q)=\frac{P(p\&q)}{P(q)}=\frac{P(p)\cdot P(q|p)}{P(q)}$$

By adapting Bayes' Theorem, Bayesians posit the following formula as a means of determining the new probability that a theory, T, is true based on the discovery of new evidence, E:

$$P_N(T)=\frac{P_0(T)\cdot P_0(E|T)}{P_0(E)}$$

This description of how probabilities changes over time, as new evidence is acquired, holds the key to more parsimonious theories being more preferable. To be clear about the meaning of the terms involved, I shall run through each of them. The term '$P_N(T)$' represents the 'new probability' of a theory once new evidence has been discovered, hence the sub-script 'N.' In the denominator, '$P_0(E)$' represents the probability that the evidence would have been observed, before it was actually observed. When this term is inverted, it comes to represent how improbable observing the evidence was, before it was observed. In the numerator, '$P_0(T)$' represents the 'prior probability' that the theory T was true before the evidence was discovered, while '$P_0(E|T)$' represents what is called the 'prior likelihood.' This '$P_0(E|T)$' factor expresses how likely the theory makes the evidence, before the evidence is observed.

To clarify the meaning of the 'likelihood' factor, let's look at an example involving flipping a coin. Theory 1 claims there is a 50% probability for both outcomes, the coin landing heads up and the coin landing tails up. Theory 2 claims there is a 100% probability for the coin landing heads up, and thus a 0% probability for the coin landing tails up. Given these theories, if the coin is flipped once and lands heads up, it can be seen that none of the three theories have been shown to be false. On the other hand, Theory 2 assigned this outcome the highest prior likelihood, since if Theory 2 is true, as the likelihood factor assumes, the coin landing heads is the only possible outcome. Theory 1 assigns the coin landing heads up a lower likelihood, and thus as a result Theory 1's new probabilities will increase by a smaller amount than that of Theory 2. Now that the terms of Bayesian formula for the new probability of a theory, after the discovery of new evidence, have been explored, it is time to explain how parsimony affects them.

It is important to note that the parsimoniousness of a theory has no impact on the prior probability of observing the evidence. In fact, the prior probability of observing the evidence is entirely independent of any theory which attempts to explain the evidence. A coin will land either heads or tails without being influenced by there existing a theory which claims it will land heads. The prior probability of observing the evidence is thus of little importance to this argument. The other factors, prior probability and prior likelihood, on the other hand are impacted by the parsimoniousness of a theory. In order to compare the affects of the discovery of new evidence on two theories, I shall compare the ratio of the two new probabilities:

$$\frac{P_N(T_1)}{P_N(T_2)}=\frac{\left(\frac{P_0(T_1)\cdot P_0(E|T_1)}{P(E)}\right)}{\left(\frac{P_0(T_2)\cdot P_0(E|T_2)}{P(E)}\right)}=\frac{P_0(T_1)\cdot P_0(E|T_1)}{P_0(T_2)\cdot P_0(E|T_2)}$$

This ratio is only impacted by the prior probability and the likelihood factor. As was just explained, the parsimoniousness of a theory has no impact on the prior probability of observing the evidence, and so its absence from the above ratio is of no consequence. I will start by arguing that more parsimonious theories experience greater increases in their likelihood factors when new evidence is discovered.[13]

As I briefly described earlier, less parsimonious theories fit a wider range of possible evidence than their more parsimonious competitors. Michael Huemer makes an excellent point that entities have a similar role for theories as adjustable parameters have for an equation. Each additional adjustable parameter in an equation allows for the equation to be a better fit for larger possible sets of data. Take three random points in the x-y plane. A linear equation, with two adjustable parameters, will have fewer sets of three such random points for which it will provide a good fit than a parabolic equation, with

13 I am only taking into consideration the affects of new evidence which is allowed for, or accounted for, by the theory.

three adjustable parameters.[14] A similar result can be found in most cases where a new entity is posited since “suppositions about each of the additional entities can be adjusted to accommodate the data” (Huemer 222). As a result, a theory with more entities can account for a wider range of observations, by accommodating more data, than a rival theory with fewer entities. However, by accounting for a wider range of observations, a less parsimonious theory assigns a lower average probability to each of the observations it allows.

To make this last point more clear, consider a theory which claims that any coin must land either heads up or tails up. This theory is compatible with, and accounts for, the observation that a coin lands heads up and the observation that a coin lands tails up. That is to say, the possible range of observations for this theory consists of the coin landing either heads up or tails up. Now taking this theory as true, then the probability of observing the coin to land either heads up or tails up is 1. This is precisely what taking the likelihood over the range of observations compatible with the theory means. So, the likelihood of the observations, given the theory, over this range is 1.

As noted earlier, a less parsimonious theory has a wider range of possible evidence, or observations. As a result, a less parsimonious theory assigns a lower average likelihood to the possible observations it allows (Huemer 223). A more parsimonious theory, on the other hand, assign a higher average likelihood to the possible observations it allows, since

14 If the three points are in roughly a straight line, the linear equation would provide a closer fit than the parabolic equation, but given a random distribution of three points in a plane they will not frequently by in a straight line. They will be scattered in a way that the parabolic bell curve could more closely fit. Adding in even more adjustable parameters will lead to even higher degrees of accuracy with curve fitting, but as pointed out this also leads to a wider possible range of evidence for which can be accounted.

it allows for fewer possible observations but still has a likelihood of 1 over the range of observations it allows. The average likelihood factor increases the probability that the theory is true. Thus, the probability that a more parsimonious theory is being true will increase by more than a less parsimonious rival, in the light of evidence for which both theories can account.

To clarify this I shall use an example similar to one Huemer uses (Huemer 223). Take a case of two theories, M and L, where M is more parsimonious than L. M equally accounts for the possible, mutually exclusive, observations O_1 and O_2, while L equally accounts for the possible, mutually exclusive, observations O_1, O_2, O_3, and O_4. Looking at the probability of observing O_1 given each of the theories, we see that $P_0(O_1|M) = ½$ and $P_0(O_1|L) = ¼$. The likelihoods say that M will be supported twice as strongly, compared to L, by the observations of either O_1 or O_2. This makes sense, since observing either O_3 or O_4 will refute M, and so M takes a greater risk with greater possible payoff. This example shows that a more parsimonious theory has a greater increase in its likelihood factory, $P_0(E|T)$, than a less parsimonious rival upon the discovery of new evidence for which both theories account. Thus, a more parsimonious theory will experience a greater increase in its new probability, $P_N(T)$, than a less parsimonious theory upon the discover of new evidence for which both theories account.

The influence of parsimony on the likelihood factor has been explored, and a positive correlation has been discovered. It appears that as the parsimoniousness of a theory increases, so too does its likelihood factor, with respect to evidence for which the theory accounts.[15] In cases where two theories have equal prior probabilities, this correlation would allow one to conclude that the more parsimonious theory is more highly confirmed by the evidence and is thus preferable over less parsimonious rivals, all else being equal. However, in the case of the two theories of Quantum Mechanics, which I will explore in Section 2, the two theories have equal likelihoods for any evidence considered. As a result, I turn to examine whether relative levels of parsimony affect the prior probabilities of competing theories, and thus influence the new probabilities of these theories. I argue that if the probability of containing the true theory is distributed over 'parsimony levels,' then less parsimonious theories will have lower prior probabilities.

An argument against more parsimonious theories having higher prior probabilities claims that such a result is the product of assuming that the world is simple (Huemer 221). This essentially claims that a bias exists in Nature towards more parsimonious theories. No such assumption need be made in order to show that more parsimonious theories have higher prior probabilities than their less parsimonious rivals. Rather, this result can be shown by assuming that the world is biased neither towards parsimony nor complexity. In this case there is no inherent bias in nature towards more or less parsimonious theories. In order to make the assumption that there is no inherent bias in Nature towards more parsimonious theories, let us examine 'parsimony levels' which are all assigned an equal probability of containing the true theory.

15 That is not to say that every theory, paired with its evidence, which is more parsimonious than a rival has a greater likelihood factor than that rival, paired with its evidence. Rather that is to claim that there is a positive correlation between parsimony and likelihood in the mathematical sense. An increase in parsimoniousness results in a increase in the likelihood factory of a theory paired with its evidence.

Based on the number of entities/events a theory posits to explain a phenomenon, each parsimony level has a numerical value. The value associated with a parsimony level reflects the total number of entities and events posited by a theory. Lower parsimony levels posit fewer entities/events and thus contain more parsimonious theories. I argue that theories belonging to lower parsimony levels have higher probabilities of being true because there are fewer theories to distribute the level's probability over at lower parsimony levels.

One might object that parsimony has a lower bound but no upper bound,"that is, for any given phenomenon, there is a simplest theory (allowing ties for simplest), but no most complex theory of the phenomenon: however complex a theory is, it is always possible to devise a more complicated one" (Huemer 219). By positing more entities/events one can devise an infinite number of parsimony levels, and so the probability assigned to each parsimony level is thus infinitesimal. It then does not matter how many theories exist at each parsimony level, since those theories will each only have an infinitesimal probability of being true. This is exemplified by the point made earlier about a linear equation describing three points in a plane. It can be seen that infinitely many more adjustable parameters could be added to fit a curve to the points, with each additional parameter increasing the parsimony level. However, one needs at least two parameters to even be able to produce a curve. This shows that there is a lower bound, but no upper bound, to the parsimony levels of theories attempting to explain a particular phenomenon. Following from there existing no upper bound on parsimony, one can argue that there exist an infinite number of parsimony levels and the theories contained in these levels will each only have an infinitesimal probability of being true.

This objection, however, is only applicable when considering *possible* parsimony levels. When one considers *actual* parsimony levels, those levels for which theories exist, one can see there is a finite number of parsimony levels. With a finite number of parsimony levels, each level is assigned a non-infinitesimal probability of containing the true theory, and thus each theory contained in these levels has a non-infinitesimal probability of being true.

Now that we have a finite number of parsimony levels to work with, and distribute probability evenly over, an additional objection arises that there still can exist infinitely many theories at each parsimony level. With an infinite number of theories existing at each parsimony level, then each theory will still have only an infinitesimal probability of being true. To this I counter that there do not exist an infinite number of theories at each parsimony level, but rather an infinite number of cases of the theories at each parsimony level. To demonstrate this point, consider a theory G which posits that two objects with mass experience gravitational attraction to one another. One case exists where G = 5, another where G = 27, another yet where G = 2000, and so on ad infinitum. There exist an infinite number of *cases* of a theory, but there do not exist and infinite number of *theories*. Cases can be collapsed to their parent theories by examining the types of entities/events they posit. If a case posits the same types of entities/events and the same number of entities/events as a theory, then it is merely an instance of that theory.

This, however, still does not show that there are not an infinite number of theories at each parsimony level, but merely distinguishes cases from theories. By examining the possible configurations of entities and events at each parsimony level (Table 1), one will see that only a finite number of theories can exist to explain a particular phenomenon.

	Parsimony Levels: 1	2	3	4
Possible Configurations	1 Entity, 0 Events	2 Entities, 0 Events	3 Entities, 0 Events	4 Entities, 0 Events
		1 Entity, 1 Event	2 Entities, 1 Event	3 Entities, 1 Event
			1 Entity, 2 Events	2 Entities, 2 Events
				1 Entity, 3 Events

Table 1: The possible configurations of number of entities and events for parsimony levels 1-4.

Let us take the phenomenon of a particle traveling in the positive *x* direction which appears to pass behind an opaque screen and comes back into view at the far end of the screen with no apparent changes having occurred behind the screen.[16] I challenge the reader to attempt to show that the number of theories possible at every parsimony level is infinite. Having undertaken this challenge, it is apparent that there exist a finite number of theories to explain a particular phenomenon at a given parsimony level. Thus, theories belonging to a parsimony level will have a non-infinitesimal probability of being true.

Additionally, it can be seen from this exercise that as the parsimony level increases, so too does the number of theories with in that parsimony level. This is a result of additional entities/events being able to cancel one another out. As an example, the particle traveling behind the screen might divert from its path, but then experience another diversion by which it resumes it original path. This theory belongs to a

16 Any phenomenon would do for this example, my choice is an arbitrary one.

parsimony level which is three higher than the theory that the particle simply continues its path behind the screen, as perhaps would be observed if the screen was not present. It has two canceling events, those involving the particle's deviation from its original path and its deviation from that new path, and one additional event, by which it resumes its original path. Two parsimony levels higher than this one, another set of canceling events can be posited. This practice can be performed repeatedly with entities/events and will result in higher parsimony levels containing a larger number of theories than lower parsimony levels. Since each parsimony level was assigned the same probability of containing the true theory, levels containing fewer theories will assign a higher probability of being the true theory to each of those theories. As a result, the more parsimonious theory will have a higher prior probability, which will increase its new probability.

In the case to be explored in Section 2, the two competing theories have equal likelihoods so the ratio of new probabilities further reduces:

$$\frac{P_N(T_1)}{P_N(T_2)}=\frac{\left(\frac{P_0(T_1)\cdot P_0(E|T_1)}{P(E)}\right)}{\left(\frac{P_0(T_2)\cdot P_0(E|T_2)}{P(E)}\right)}=\frac{P_0(T_1)\cdot P_0(E|T_1)}{P_0(T_2)\cdot P_0(E|T_2)}=\frac{P_0(T_1)}{P_0(T_2)}$$

Whichever of the two theories is more parsimonious, all other things equal, will have a higher prior probability. This will increase its new probability and the ratio of new probabilities will reflect the increase. The more parsimonious theory will be more probable, and thus preferable.

In conclusion, relative levels of parsimony affect the new probabilities of two competing theories such that the more parsimonious theory is more probable, all else being equal. It should be incontestable that choosing a more probable theory over a less probable theory is a justified choice to make. It would seem highly unreasonable to prefer a less probable theory, and thus unjustified on epistemological grounds. Thus one should prefer a more parsimonious theory over a less parsimonious rival, all else being equal. In the next section I proceed to apply this finding to the specific case of two interpretations of Quantum Mechanics, the Copenhagen interpretation and the Bohmian interpretation.

Section Two: Analysis of the Interpretations

I now look at how the Copenhagen and Bohmian interpretations account for the results of the double-slit experiment, as described in the Introduction. I analyze these accounts for relative parsimony levels[17], and conclude that the Bohmian interpretation is more parsimonious than the Copenhagen interpretation and should be preferred. For clarity, I will italicize those entities/events which contribute to the parsimony level of each interpretation.

Under the Copenhagen interpretation of Quantum Mechanics, particles exist but without any definite characteristics until measurement. The particle, however, is completely described by its wave function. The wave function is a superposition of all of the possible quantum states for the particle. This means that, in terms of position, the wave function can be used to find the probabilities for each possible position of the particle. In the double-slit experiment, before the *particle* strikes the photographic paper it cannot be considered to be in any particular position, but rather in a superposition of possible position states. The particle is simultaneously in every possible state, and in none of them in particular. Upon an interaction with the photographic paper, the wave function collapses to reflect the certainty with which the position is now known. The presence of a *measuring device*, here the photographic paper, results in the wave function *collapsing*. Without a *measurement*, there would be no impetus for the wave function to collapse, and the particle would remain in a superposition of states. The interference

17 As explained in Section One, the number associated with a parsimony level reflects the total number of entities and events posited by a theory or interpretation. Lower parsimony levels posit fewer entities/events and are thus more parsimonious.

pattern observed in the double-slit experiment is the result of measuring the position of particles, according to the Copenhagen interpretation.

Thus, it seems that the Copenhagen interpretation posits the following: two physical entities (the particle/wave function, and the observer/measuring device), and two events (the measurement of the particle, and the collapse of the wave function). That puts the Copenhagen interpretation at a parsimony level of 4.

Alternatively, under the Bohmian interpretation of Quantum Mechanics, particles exist with definite positions and their own guiding wave functions. In the double-slit experiment, the *particle* passes through one slit or the other, as a classical particle would, but its motion is determined by the wave function which has passed through both slits. The *quantum field*, characterized by the wave function, passes through both slits and interferes with itself, producing a complicated quantum potential on the other side (Figure 5). The quantum potential acts upon the particle and determines the possible trajectories for its corresponding particle (Figure 6). Each particle *strikes the photographic paper* in accordance with a possible trajectory, and these trajectories create the interference pattern that is observed in the double-slit experiment.

Thus, the Bohmian interpretation posits the following in its explanation of the double-slit experiment: two physical entities (the particle, and the wave function), and one event (the particle striking the photographic paper). That puts the Bohmian interpretation at a parsimony level of 3.

From this analysis, and the argument laid out in Section One, the Bohmian interpretation is more parsimonious that the Copenhagen interpretation. The Bohmian interpretation should thus be preferred over the Copenhagen interpretation as the more probable interpretation.

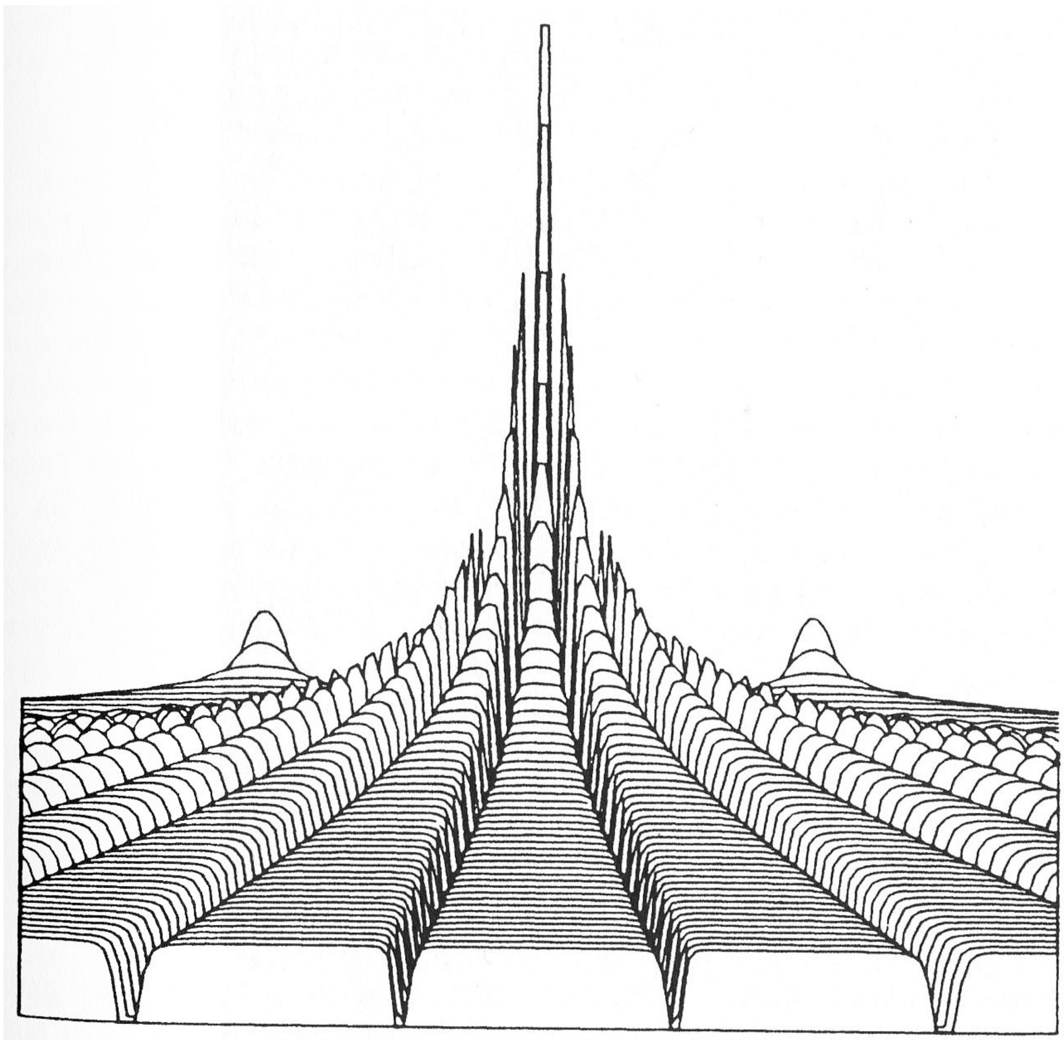

Figure 5: The quantum potential after the wave function passes through the double-slit apparatus. Taken from Jim Baggott in *The Meaning of Quantum Theory*, 163.

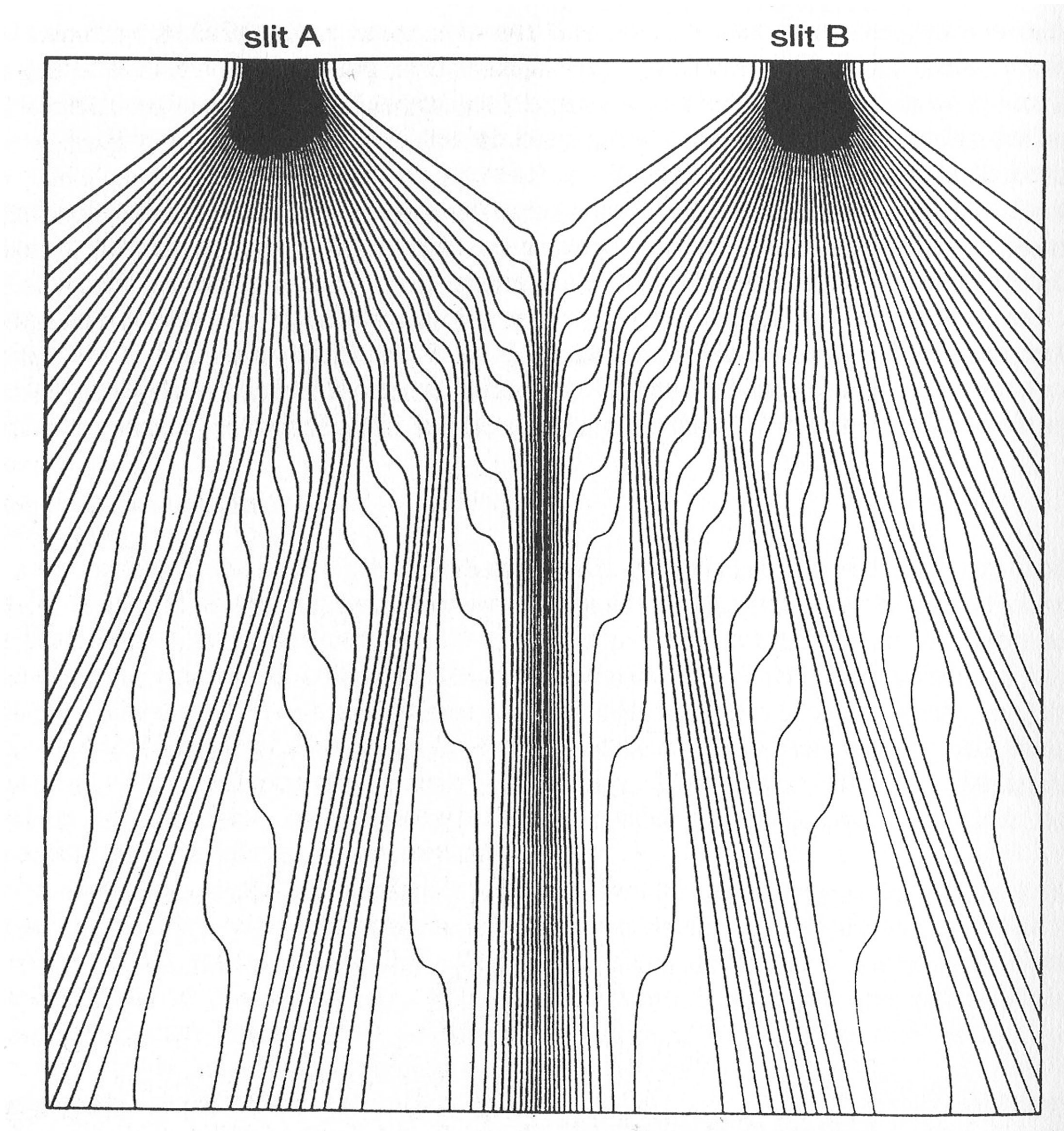

Figure 6: Theoretical trajectories for an particle passing through the double-slit apparatus, calculated using the quantum potential in figure 5. Taken from Jim Baggott in *The Meaning of Quantum Theory*, 164.

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