What is wrong with action at a distance?

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Abstract

This thesis aims to legitimize the inclusion of action at a distance in scientific theories. I approach this task from two angles. In the first part, I show that action at a distance is a genuine metaphysical possibility. To do so, I examine how theorists in the history of science have justified their assumption of locality (and find these justifications inadequate), reconcile action at a distance with scientific explanation and show that it is not a threat to causation. In the second part, I consider an actual instance of action at a distance in nature: quantum nonlocality. Since action at a distance cannot be excluded through reason alone, if experience indicates action at a distance one may call it as such. I argue that action at a distance is the most viable theory by which to interpret quantum nonlocality.

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Introduction

What's wrong with action at a distance? In the middle of the 20th century scientific theorists were forced to address this question head on. Experimentation in quantum mechanics had confirmed quantum nonlocality, a phenomenon that appears to be an instance of action at a distance. Despite empirical indication, physicists and metaphysicians remain hesitant to accept action at a distance as an aspect of fundamental reality. In this paper, I argue that this hesitance is not justified; locality is a metaphysical assumption that should be seriously questioned, especially in the face of well confirmed scientific evidence that it is an erroneous one.

In part one of this paper I show that there is no a priori reason to exclude action at a distance from scientific theories. A survey of several attitudes towards action at a distance from the history of science reveals that locality has been assumed without justification based on an unexamined conviction that action at a distance fails to explain phenomena in a satisfactory way and gives no causal account. Actually, action at a distance can be reconciled with the deductive-nomological model of scientific explanation. To address worries relating to causality, I show that a regularity theory of causality allows for distant action.

In part two of my paper I consider two interpretations of quantum nonlocality that avoid action at a distance: superluminal causation and holism. Superluminal causation poses significant conceptual difficulties because it is incompatible with special relativity. Holism is too obscure to advance the explanation of quantum phenomena either scientifically or metaphysically. In fact, it reduces to an embellished version of action at a distance upon careful evaluation.

Action at a distance is not only possible, it is also the best available theory to account for quantum nonlocality.

Part I

1. A brief historical overview

In this chapter I consider attitudes towards action at a distance taken throughout the history of science by theorists. What sort of justification have scientists given for assuming locality in their scientific theories? First, I will consider Aristotle's discussion of action at distance so as to provide an example from ancient natural philosophy. Next, I examine the views of several early modern scientists regarding action at a distance. Finally, I look at how modern physics has addressed the issue. I find that there is very little offered in the way of formal argumentation in favor of locality and against action at a distance. Scientists and philosophers treat locality as a metaphysical principle. Mary Hesse states that locality, like all metaphysical statements, is a "[generalization] from familiar experience, or from a familiar stock of ideas, applied analogically to the fundamental structure of nature" (1955, p. 337). I argue that this method is not sufficient for excluding action at a distance from scientific theories.

1.1 Action at a distance and ancient science

Aristotle, in the *Physics*, states that "that which is the first mover of a thing – in the sense that it supplies not that for the sake of which but the source of the motion – is always together with that which is moved by it (by 'together' I mean that there is nothing between them)" (*Physics*, Bk VII: 2). He goes on to defend this claim by arguments from definition and from induction.

It is obvious, Aristotle says, that things which are moved by themselves are together with that which moves them; this requires no detailed argument. Movement caused by something other than the thing itself can be reduced to either pushing or pulling. The definitions of pushing and pulling, he claims, prove that all motion is together with that which causes its motion. The argument may be presented as follows:

Definitions:

(1) Pushing is motion to something else from oneself or from something else.

(2) Pulling is motion from something else to oneself or to something else, when the motion of that which is pulling is quicker than the motion which would separate from one another the two things that are continuous.

Premises:

(3) All motion from something to something else is either pushing or pulling.

(4) It is impossible to move anything either from oneself to something else or from something else to oneself without being in contact with it.

Conclusion:

(5) In all locomotion, there is nothing between moved and mover.

It is worth noting that although Aristotle defends locality, it is of a different kind than that which pervades the modern mechanical world view. Telos is essential to Aristotelian physics; matter is thought to have an internal purpose which drives its movements, unlike the external force-based understanding of matter that is fundamental to modern science. Given this, Aristotle does not exclude a soul or a tendency from being a local mover. Motion for Aristotle is not strictly physical bodies acting upon each other. Still, regardless of that which acts as a mover, the general principle of locality is stated in the above argument.

The argument from definitions is circular, as premise (4) is a reformulated statement of the conclusion. Aristotle is relying on intuition[1] rather than reason to make his claim against action at a distance. Christopher Decaen, in his analysis of Aristotle's argument for locality, suggests that "Aristotle's goal here is not to demonstrate this proposition, but to dispose the student's mind to grasp the truth of it" (2007, p. 188). That is, to appeal to the intuition of the student. This intuition is a generalization of how humans can cause change. Pushing and pulling imply an actor with a will, a human or an animal. Aristotle's strategy is to make an analogy from our perceptual experience to action in principle. Decaen reads Aristotle as holding that "the impossibility of action at a distance is something one can gather through the appropriate survey of experience" (2007, p. 185). The argument from definitions does not give locality a firmer footing than admitting that it is a strong intuition given a certain interpretation of perceptual experiences.

It can be induced, according to Aristotle, that there is nothing intermediate between the moved and the mover. I interpret 'nothing intermediate' to be an equivalent statement to nothing being between the mover and moved. Aristotle claims that "in every case we find that the respective extremities of that which causes and that which undergoes alteration are together" (*Physics,* Bk VII: 2). Given that we always observe in every case that the mover is together with the moved, one can induce a general principle.

Aristotle goes on to support this induction by listing examples of local action, including our perceptual experiences. According to his theory of perception, color is in contact with light which is in contact with the eyes and smell is in contact with air which is in contact with the

[1] Here, and for the remainder of this paper, I am using 'intuition' in a colloquial sense. By 'intuition' I mean to believe something based on an instinctual feeling instead of through logical deliberation.

nostrils. Both serve as instances of local action. The motion of falling (due to gravity) is a tendency according to Aristotle, and thus action at a distance is easily avoided in that case: tendencies are self-movement. Aristotle explains phenomena which could naturally be described by action at a distance (like sight and falling downward) through local means because a metaphysical assumption has already been made banning action at a distance.

To sum up, Aristotle gives no convincing conceptual arguments in favor of locality. He instead appeals to certain perceptual experiences to reinforce an intuition against action at a distance. If we are to approach action at a distance in a neutral way, we must ban such intuitions from deterring us from accepting a scientific theory which is otherwise virtuous.

1.2 Action at a distance and early modern science

Aristotle's natural philosophy prohibited action at a distance, but Aristotelian views of motion and matter hold little sway today. The mechanistic philosophy of the scientific revolution is still related to the general scientific goals and methods of modern science, however. To trace the various attitudes towards action at a distance espoused throughout the 17th, 18th, and 19th centuries, I will draw from Mary Hesse's historical scientific account (1955) which spells out the issues in a particularly clear and precise manner. As science became increasingly empirical, the dogmatism against action at a distance became more and more difficult to defend, although the intuition that the final theory of matter would be local remained for most theorists.

Hesse uses the term 'mechanical theory of matter' (1955) to refer to early modern scientific thought, the forbearer of modern empirical sciences. Early modern scientific thought is partly signified by a transition from teleological explanations of phenomena (like those given by Aristotle) to explanations in terms of "communication from the outside" (Hesse, 1955, p. 337). Mechanics (physics) became the fundamental scientific field, and action (and what exactly it comprises of) became more important than before for scientific theorists. Initially, the emphasis on action strictly excluded action at a distance because theories were sought (such as Descartes' physics) which reduced everything to action by impact.

Outspoken opponents of action at a distance in the early period of the scientific revolution include Leibniz and Descartes. According to Hesse, Leibniz criticizes action at a distance on the grounds that those who postulate it have returned "to the Aristotelian habit of postulating an *ad hoc* quality for every new phenomenon, without showing that the quality explained the phenomenon in any way by relating it to other processes of nature" (1955, p. 339). In the early modern scientific period, action at a distance was considered archaic because it did not conform to the explanatory criteria of contemporary science which had proven successful, for example: Newton's laws of impact.

However, the movement towards an empirical natural science threatened the strictly mechanical account of fundamental reality that was so eagerly sought: "metaphysical objections to action at a distance lost most of their plausibility" (Hesse, 1955, p. 341). Three different theories of action were developed in tandem with empirical progress: action by impact, action in a continuous medium, and action at a distance (Hesse, 1955). All three contributed to successful scientific progress in the seventeenth and eighteenth centuries and continue to contribute to modern developments by their extension to new areas of research. Action at a distance was included in scientific thought because of phenomena like electromagnetism and gravity, but few theorists espoused a belief in the finality of theories that appealed to action at a distance.

As physics became modernized, mathematical descriptions of phenomena became more advanced and picturesque theories of fundamental reality became less meaningful. Hesse illustrates this transition by drawing attention to the struggle (of Faraday, Maxwell, and others) to find an adequate mechanical description of electromagnetic phenomena (Hesse 1955: 347-350). In the 19th century:

> "mechanical models of theories are still sought, but it is clear that in terms of these no answer to the mechanical problem of action is possible. The reason for this is that the mechanical models are no longer thought of as literal descriptions of entities in existing nature, but as interpretations, in terms of mechanical devices, of phenomena that are described mathematically but whose ultimate nature cannot be regarded as crudely mechanical" (Hesse, 1955, p. 347-348).

Isaac Newton heralded this movement in physics in his *Principia*. Newton resists grand material descriptions (such as those of Descartes) in favor of mathematical descriptions of empirical facts. He espouses at length in his General Scholium his belief in the ultimate inaccessibility of nature: "in bodies we see only their figures and colors, we hear only the sounds, we touch only their outward surfaces, we smell only the smells, and taste the savors; but their inward substances are not to be known, either by our senses, or by any reflex act of our minds" (Newton, 1729, p. 390). Explicitly concerning whether gravity is a case of action at a distance or whether a mechanical account of it can be formulated, Newton states "I frame no hypothesis" (1729, p. 390)**.** Newton considers the bare mathematically accurate description of gravitational forces to be explanatory enough (in contrast to a thinker like Leibniz, who seeks a full mechanical picture).

Despite the push in physics towards more mathematical descriptions and less mechanical ones, the metaphysical distaste for action at a distance as a final explanation persisted. Well into the 19th century, James Maxwell developed a mechanical model which relied on an unsubstantiated ether to explain electromagnetism. An ether of some sort was frequently posited throughout the history of science to avoid surrendering to action at a distance. The lack of evidence for an immaterial ether (as well as the incomprehensibility of such a thing) is a testament to the reluctance of theorists to abandon the metaphysical principle of locality.

Although several aspects of macro experience hint at action at a distance (for example, perception does not seem like a mechanistic process), a mechanical theory of matter disregards perceptual experiences. Instead, machines, which operate roughly according to laws of impact, serve as an analogy for all of nature. Phenomena which do not easily conform to a mechanistic explanation are assumed to contain inner mechanisms (hidden from plain sight) that do. A review of the history of early modern science reveals that the more advanced physics becomes, the more difficult it is to cling to locality in the practice of science. The conviction that action at a distance cannot serve as a satisfactory account of reality persisted even as empiricism suggested otherwise, however, and still persists.

1.3 Action at a distance and modern physics

The question of whether locality is a necessary metaphysical assumption in physics gained renewed importance in the beginning of the 20th century. Quantum mechanics predicts several unexpected results which challenge basic assumptions in classical physics, including locality. A notorious debate took place at this time between Niels Bohr, who defended the completeness of quantum mechanics, and Albert Einstein, who believed that the unusual predictions indicated that quantum mechanics did not accurately account for every aspect of reality. I discuss the EPR thought experiment and the experimental discoveries in quantum mechanics that are pertinent to action at a distance in part two of this paper. Here, I will consider Einstein's justification for locality (as presented in his 1948 paper "Quantum mechanics and reality"), an example of the locality assumption in modern physics.

Einstein is a realist about physics. This realism serves as motivation for rejecting indeterminacy relations in quantum mechanics; he believes that reality could not possibly be dependent on observation or be indeterminate in such a fundamental sense: "the concepts of physics relate to a real outside world, that is, ideas are established relating to things such as bodies, fields, etc., which claim a 'real existence' that is independent of the perceiving subject" (Einstein, 1948, II). This commitment to realism is understandable enough, and Einstein stops short of claiming that ideas must be identical with reality. He only claims that ideas are in a secure relationship with those things that 'really are'.

To defend locality, Einstein appeals to the fact that it is an idea that is entrenched in the fundamentals of our physics. He asserts that "an essential aspect of this arrangement of things in physics is that they lay claim, at a certain time, to an existence independent of one another, provided these objects 'are situated in different parts of space'" (1948, II). Given what he has said regarding the reality of physics, the justification for locality lies in the fact that it is a respected principle within physics. Elaborating on his locality claim, Einstein mentions that the assumption that objects removed in space are independent from one another "stems in the first place from everyday thinking" and that without it "physical thinking in the familiar sense would not be possible" (1948: II). The argument employed by Einstein is both an appeal to intuitions based on certain experiences (as Aristotle does) and the assertion that if locality is assumed by successful scientific theories then it must correspond to something real.

The first aspect of Einstein's defense (that everyday experience teaches us locality) has already been addressed regarding Aristotle. The second aspect (that physics can only work if the world is local so the world must be local) is interesting in light of the previous discussion of action at a distance in early modern science. Action at a distance has not been absent from physics: it has been utilized to explain gravitational force and electromagnetic phenomena. The inclusion of action at a distance in scientific theories has not put an end to scientific exploration and does not prevent theories from being tested. Einstein's insistence that physics must be local counters the complicated relationship between physical theories and action at a distance which one witnesses upon careful historical review.

2. Reconciling action at a distance with explanation

In this chapter I consider whether action at a distance can be satisfactory explanation of phenomena. I discuss above why locality has been accepted more or less unquestioningly throughout the history of science, and come to the conclusion that the locality conviction is not based on necessity by argument; rather, it is a metaphysical assumption which arises from common intuitions and scientific paradigms. Because of this metaphysical assumption, scientific theories which appeal to action at a distance are considered to be lacking in explanatory power. I aim to show that action at a distance can do explanatory work within science.

First, I consider what explanation is taken to mean in a general sense. Next, I approach the issue of explanation (and whether action at a distance can be taken as a satisfactory explanation for phenomena) from a scientific perspective. I consider two accounts of scientific explanation: Carl Hempel's deductive-nomological account (1964) and Wesley Salmon's causal mechanical model (1984). I have chosen these theories because they stand in stark contrast to each other. Hempel's theory is a logical empiricist account that avoids reference to causation while Salmon's reduces explanation to a description of causal processes. Action at a distance can be reconciled with Hempel's theory of explanation but is in direct contradiction with Salmon's causal mechanical model. I criticize Salmon's model on the basis of its blind adherence to a naïve mechanical worldview which is burdened with unnecessary metaphysical assumptions about reality and claim that action at a distance can be a satisfactory scientific explanation of phenomena.

2.1 A rough and ready conception of explanation

Explanation stands in contrast to description. Parsing out the details of this contrast is crucial to understanding what is required of explanation. It is possible to accurately and truly give a descriptive account of a phenomenon without providing an explanation of that phenomenon. Explanations go beyond what is true: they must respond to a 'why' question. The 'why' question addressed by explanation usually relates to the development of a phenomenon (causal or temporal). The sort of 'why' question to which an explanation provides a response can vary significantly according to perspective and epistemological goals. Because of this variance, appealing to the notion of 'why' is not enough to develop a precise notion of explanation.

Explanation is related to understanding; it is obvious that a good explanation will increase our understanding of that which is explained. Understanding is a concept that is just as difficult to characterize as explanation, however. It is epistemological: if something is understandable it is reconcilable with the framework of other things we understand. It should be in a 'language' we are already familiar with. Explanation must fit into our conceptual toolbox to be of any use to us. On the other hand, if an explanation corresponds exactly to what is already familiar it is not interesting or explanatory at all. Explanation is related to discovery: we *discover* explanations for phenomena, and it is the slightly surprising quality of the explanation which makes it satisfying.

To sum up the preliminary notion of explanation which I have sketched above: we expect explanations to answer 'why' questions, to increase understanding, and to provide new, unexpected insights. The trouble with this rough idea is that the 'why' questions which are of interest to us change based on the metaphysical framework which guides inquiry. To illustrate: in chapter 1, I discussed the early modern impulse to only accept mechanical explanations (an account of inner mechanisms) as satisfactory. In contrast, Aristotelian natural philosophy sought teleological explanations. That which is considered a satisfactory explanation in one framework may be rejected in the other.

To evaluate the explanatory power of action at a distance in science, a theory of scientific explanation which is most faithful to the phenomena and most distant from metaphysical assumptions must be sought.

2.2 Theories of scientific explanation

Deductive-Nomological Model

Carl Hempel's deductive-nomological (DN) model of explanation is a promising starting point for uncovering such a theory. An ideal scientific explanation, according to Hempel's theory which was developed in collaboration with Paul Oppenheim, consists of explandandum and explanans (1948). The explanandum is a sentence which describes the phenomenon to be explained. The explanans is a sentence which gives an account of the phenomenon. The explanandum must be deducible from the explanans. The explanans must be true and must contain at least one law of nature.

Immediately, a difficulty arises related to laws of nature. Hempel does not give a full satisfactory account of how to differentiate between laws and less essential regularities. How can one exclude in principle the generalization that 'there are no balls of sugar larger than one mile across' from the category of natural law? Furthermore, without appealing to causal relationships, how can one determine whether the law of nature which is a part of the explanans is related in an interesting way to the explanandum? Hempel fills out the notion of law by defining a law as an exception-less generalization of non-coincidental regularities. This definition still requires that one judge intuitively whether a regularity is a natural law or not. There is no cut and dried way to evaluate whether a regularity is coincidental. The law problem in the DN model of explanation is of most significance to biology, and less for physics, however. Other issues with the DN model include undesirable symmetry, difficulties in dealing with probabilistic laws, and failure to account for all satisfactory explanations (Woodward, 2003). Because the DN model intentionally avoids appealing to causal relations in order to explain, there is no way to prioritize cause over effect. The height of a flag pole can be explained by the length of its shadow. To qualm fears regarding explanations which appear NOT to follow the DN model but are satisfactory, Hempel uses the hidden structure strategy: he argues that the DN model is implicit in explanations where it is not explicit. Woodward (2003) criticizes this approach as nonsensical because explanations are meant to increase explicit understanding. How could implicit explanatory power increase explicit understanding of a phenomenon?

The DN model of explanation is particularly applicable to physics because it does not require a material explanation of phenomena. Mathematical laws applied to initial quantities resulting in a specific phenomenon is the ideal case of a deductive-nomological scientific explanation. Logical empiricists like Hempel aim to eliminate causal relations and to separate theory from explanation. Wesley Salmon suggests that logical empiricists hold a view in which "the main idea [is] that at the most basic level we have the particular empirical facts revealed by observation, at the next level are empirical generalization concerning observables, and at the next higher level theories that seem to make reference to unobservable entities" (1989, p. 123). The motivation for separating explanation (based on general, often mathematical laws) from physical theories is clear enough if one considers the history of science. As discussed above, physical theories were taken to be analogical as mathematical explanations of phenomena gained success.

Causal Mechanical Model

Unsatisfied by the austere logical empiricist formulation of explanation put forth by Hempel, Wesley Salmon advocates for a theory of explanation which relies on causal relations.

Salmon recognizes that Hempel's account of explanation seeks to define explanation in terms of description; to show that "explanatory knowledge is part of our empirically based descriptive knowledge of the natural world" (Salmon, 1989, p. 127). Salmon criticizes this as too reductive. Explanation must be something over and above description (Salmon, 1989).

Salmon eschews the Humean skepticism of cause espoused by the logical empiricists and instead is insistent on causal realism. He calls his model of explanation the 'ontic conception' (1984); he believes real causal relations in nature should be used (and are typically used) to provide deep explanation of phenomena. Bringing causal relations into explanation solves many of the problems that the deductive-nomological model faces. For example, causal relations can clear up the asymmetry issue and can provide criteria for determining which universal laws are relevant to a phenomenon.

Salmon fills out the notion of causal processes by appealing to marks (1984). Genuine causal processes can be recognized because they are physical processes which transmit marks. Marks are traceable effects left by the interaction of two objects that persist in time. The model for causal interaction in the causal mechanical model is action by impact; for example, the collision of two balls (Woodward, 2003). Although causal processes are utilized in this view to avoid the issue encountered by Hempel of how to determine which laws are relevant to an explanation, the notion of causality turns out to be too ill-defined in this formulation to provide clarity. If one tracks causal processes by marks alone, there is still no criteria by which to distinguish which causal processes are relevant to an explanation.

There is a serious drawback to the causal mechanical model of explanation which Salmon himself acknowledges (1984). The experimental results of quantum mechanics suggest that there is no causal relation of the sort Salmon refers to at the most fundamental level of explanation. To sidestep this problem, Salmon admits that "it may turn out that the causal conception of scientific explanation has limited applicability" (1984, p. 298). Salmon insists that the problem isn't fatal, but if his theory is not applicable to all phenomena then it loses its draw. Salmon's model of explanation depends upon causal realism to provide criteria for deciphering relevant general laws. To admit that these causal relations do not hold at one level of explanation calls into question their reality.

Salmon's causal mechanical model of explanation is far too dependent on the early modern mechanical theory of matter which I evaluate in chapter 1 of this paper. The mechanical theory of matter proved insufficient as physics advanced into the realm of things unobservable by the naked eye, and scientists began to view physical theories as analogical. Salmon does not adequately justify his conviction that there do exist causal relations which can guide our explanations. The fact that a successful modern scientific theory (quantum mechanics) cannot be considered explanatory by Salmon's account suggests that it fails to heed how science explains things in practice.

Salmon asserts that:

> "instead of asking whether we have found reasons to have expected the event-to-be-explained had the explanatory information been available in advance, we focus on the question of physical mechanisms. Scientific understanding, according to this conception, involves laying bare the mechanisms- etiological or constitutive, causal or noncausal- that bring about the fact-to-be-explained." (1984, p. 301)

He presents this as a step forward, beyond the logical empiricist formulation of explanation. The causal mechanical model of explanation is actually a step backwards, towards the more dogmatic and metaphysical mechanical theory of matter of early modern science.

The deductive-nomological model of scientific explanation is flawed, but most of its flaws are only pertinent to scientific fields that are not physics. Furthermore, it is an account of explanation which avoids metaphysical commitments, unlike an account which depends on causality or the mechanical theory of matter. The deductive-nomological model is unconcerned with mechanical models, and this corresponds well with how science has been practiced since the 18th century, when mathematical theories began to take precedence.

Action at a distance has been considered in the history of science unable to adequately explain phenomena. This intuition has been expressed from Leibniz to Einstein. If one adheres to a causal mechanical model of explanation, action at a distance clearly does not conform to the criteria of a satisfactory explanation: the notion of cause Salmon appeals to is mechanical. Spatially continuous marks are assumed to signify the causal relations which are then employed in explanation. However, accepting action at a distance does not undermine the goals of scientific explanation. Action at a distance can operate in conformity with the deductive-nomological model of explanation put forth by Hempel. There is nothing in Hempel's account which prohibits natural laws from connecting distant events. The extensive and rigorous literature within philosophy of science exploring the purposes and expectations of scientific explanations has proved fruitful in finding a detailed account of explanation for which action at a distance poses no problem.

3. Reconciling action at a distance with causality

In the previous chapter, I discuss scientific explanation to reconcile action at a distance with a satisfying notion of explanation. Explanation is closely tied to causation, as one can glean from the causal mechanical model put forth by Salmon. The deductive-nomological theory of explanation fits nicely with action at a distance partly because it avoids appealing to causation to define explanation. Carl Hempel, a logical empiricist, actively seeks to avoid defining explanation in terms of causation, and adheres to a regularity theory of causation in the style of David Hume. In this section of my paper, I address head on what sort of causation can be salvaged if we allow action at a distance into our science and our metaphysics.

In chapter 1, I identify why action at a distance has been viewed with suspicion throughout the history of science. Although no convincing argument from a priori principles can be made against action at a distance, the prejudice against it is based upon the conviction that action at a distance is not explanatory within a modern scientific framework, that it can be seen to be false from experience, and implicitly, that it fails to align with our firm belief in how causality works[2]. To what extent can we trust our experience to give us certain truths about the fundamental nature of reality? And do we have a firm enough conception of causality to reject action at a distance based on its failure to conform to that conception?

David Hume provides a promising starting off point by which to thoroughly investigate causality, especially considering the impact his analysis of causality has had on contemporary philosophy of science and the logical empiricism of Carl Hempel. Working from Hume, I

[2] As I have discussed and shown in chapter 2, the reason that action at a distance is seen as having no explanatory power relates to how we view explanation. If we require explanation to give an account of causal relations (and I believe this how we typically but mistakenly understand explanation), then action at a distance fails. Thus the lack of explanatory power can ultimately be reduced to action at a distance's inability to show causal relations.

address the questions I present above. First, I give an account of Hume's theory. Second, I apply his theory to action at a distance. I show that locality cannot be derived purely through reason. It is a matter of fact which we learn through experience, but given the status of causality, there is nothing which necessarily commits scientific enquiry to locality. Action at a distance cannot be ruled out by metaphysics, and if one encounters it in experience then one may accept it as actual.

3.1 An explication of Hume's theory of causality

Hume begins his investigation into causality by separating matters of fact from relations of ideas (1748). Relations of ideas are those principles which can be derived from thinking alone. Euclid's geometry, even if it does not correspond to the facts about nature, is still true because the propositions follow from the axioms, postulates, and definitions which he sets out. Based on Euclid's axioms, postulates, and definitions there are clear deductions and contradictions. On the other hand, matters of fact are found to exist in nature. Hume argues that there is no way to determine matters of fact about nature through ideas: "absolutely all the laws of nature and operations of bodies can be known only through experience" (1748, p. 13).

Hume argues for this by pointing to effects which are unexpected, such as the explosion of gunpowder. One can remember when one discovered that this effect would result from this cause, and remember that it was by experience that the causal connection between gunpowder and explosions was made. Once this connection is learned through experience, there is no absolute principle to which we can trace back the connection, and the only reason for believing in the causal connection between gunpowder and explosion is experiential. Perhaps we can explore deeper into a phenomenon, but the nature of the connection is never accessible to us.

Euclid's geometry is certainly true because we are aware of the axioms, postulates, and definitions from which we may begin. The axioms, postulates, and definitions of nature are either unknown or nonexistent. Hume asserts that the "ultimate sources and principles are totally hidden from human enquiry" (1748, p. 14). He believes that one should not hope to ever discover these principles, because there is no known avenue in science by which one can hope to penetrate the ultimate principles of nature. We are restricted, in our enquiry, to making observations and generalizations based on experience alone[3].

That which allows us to imagine real causal relations between two regularly conjoined events is called necessary connection by Hume. Succession and constant connection are matters of facts which can be observed to exist between two events (Rosenberg, 1981). Observing these things pushes the observer in the direction of making an inference that one event will probably happen in succession of and because of another event. Necessary connection allows the observer to make the leap from probability to a causal relation.

Alexander Rosenberg (1981) asserts that Hume's primary task is to trace necessary connection to its origin. Only by doing so can one understand the status of causality (whether causal relations exist in nature or are mind dependent). Rosenberg is hesitant to admit that Hume's theory eliminates necessity from nature: "Hume certainly wishes to deny that there is any necessary connectedness between objects themselves. But does he wish to deny that a genuine *cause* is in any sense necessarily connected with its effect?" (1981, p. 6) Judging by *An enquiry into human understanding*, this is exactly what Hume wants to deny. It is the nature of

[3] Do we not become increasingly acquainted with the ultimate principles through our experience of nature? Hume insists that by the strict rule of reason, experiences are of a different kind than ideas, and thus the two may not intermingle. To learn from experience, we must experience the same thing many times. On the other hand, to learn from reason we must encounter something only once: "all inferences from experience, therefor, are effects of custom and not of reasoning" (Hume, 1748, p. 20).

the acting force itself, the causal connection independent of the objects on which it acts, which is shrouded in mystery.

Hume associates necessary connection with power and energy. We believe in forces, and this allows us to believe in necessary connection. If Hume were to maintain some necessity in cause itself, it would have to be through a certain belief in the existence of power, energy, or force. If these existed, then there would be an agent of causation (separate from an object) which maintained necessity in some sense in the actual world. Hume does not consider 'power', which we depend upon in order to establish necessary connection, to be accessible to human enquiry: "throughout the whole of nature there seems not to be a single instance of *connection* that is conceivable by us. All events seem to be entirely loose and separate" (1748, p. 36). Hume eliminates necessity (in any sense which is understandable to us) from nature by claiming that which we imagine acting between events (force, power) is at the very least beyond understanding and at most nonexistent.

Necessary connection, then, is a habit of thought which allows us to make the jump from probability to necessity regarding causal relationships by positing force, energy, or power. The true nature of these concepts is completely obscure, regardless of the depth of our scientific enquiry into nature. One only expands experiential knowledge of events, but never encounters a principle which completes human understanding of causation by elucidating the acting power which necessitates an effect.

One could object that the progression of science brings human enquiry closer and closer to understanding force and power. Atomic physics certainly fills out to some degree our knowledge of how energy is transferred, and the discovery of energy particles like photons and electrons seems to add concreteness to the idea. However, the status of the unobservable realm is controversial, and perhaps our knowledge of unobservables is analogical as opposed to ontological. Even considering modern advancements in physics, Hume's suggestion that power is inaccessible to human enquiry can be justified.

Hume provides two possible definitions for cause which do not rely on necessary connection (1748). The first is:

(1) An event followed by another, where all events similar to the first are followed by events similar to the second.

And the second is:

(2) An event followed by another, where the appearance of the former always conveys the thought of the latter.

The second definition is perhaps more skeptical than the first, in that is hesitates to venture outside the mental processes of the observer. But in both, succession and regularity (constant connection) are important. These two principles alone are enough to justify (as much as is possible) a scientific theory. Any theory which claims to rely on necessary connection, according to Hume's view, is in fact no more justified than a theory based purely on succession and regularity.

Moving forward, I consider causation to be based purely on facts of that matter: succession and regularity. Necessary connection, a psychological habit of human enquiry, need not be present to establish a cause and effect relation. Given that there is no rational basis for necessary connection in the first place, the absence of necessary connection should not be considered harmful to a scientific theory. Instead, to preserve causation (in a somewhat weakened sense) one must take up a regularity theory: regularity even in the absence of necessary connection is all one can hope for to establish causal relations in one's scientific theories.

3.2 Applying Hume's theory to action at a distance

Having formulated a working interpretation of Hume's theory of causation, I now consider whether action at a distance can be reconciled with a regularity theory of causation. I conclude that not only can Hume's theory be neatly applied to action at a distance, but his explication of necessary causation sheds light on the locality assumption. Another hurdle has been bypassed in the effort to legitimatize action at a distance; a theory of causation has been found with which it can coexist.

Initially, succession seems to pose a serious issue for action at a distance. Since action at a distance does not travel from one place to another via a medium, instantaneous action is a possibility. Instantaneousness makes it impossible to differentiate the cause from the effect temporally. Without asymmetry, causality is lost. According to Hume, it is exactly this asymmetry in experience (observing that one thing consistently follows from another) that gives us a firm basis for inferring a regularity. Without the ability to establish at least a regularity, scientific enquiry is impossible. It is in the best interest of science, then, to preserve a weak notion of cause that reflects how cause is experienced; the effect results from the cause.

Succession can be preserved if temporality is removed from the notion of causal succession. Hans Reichenbach establishes a nontemporal definition of causal sequence in order to avoid problems related to causality in relativity theory (1958). The distinction he makes between causal order and time order can provide a solution in this case, too. Reichenbach defines causal order in the following way:

"If E_1 is the cause of E_2, then a small variation (a mark) in E_1 is associated with a small variation in E_2, whereas small variations in E_2 are not associated with variations in E_1" (1958, p. 136).

This is enough to give an account of the asymmetry we experience regarding cause and effect without depending on time passing to establish the succession[4].

Action at a distance can exhibit regularity. Instances in which action at a distance has been posited in the history of science (such as gravity and electromagnetism) can be defined by mathematical laws.

Hume's explication of necessary connection is helpful for determining how and why locality has been so tenaciously assumed throughout the history of science. Necessary connection suggests that a deep knowledge of the mechanisms of causal processes is within reach. Locality relies on a picture of the world in which the inner mechanisms of phenomena can be understood in terms of metaphysical assumptions related to the early modern mechanical theory of matter. If one considers, as Hume does, powers to be inaccessible to human enquiry, this derails the way inner mechanisms are thought to exist for a mechanical theory of matter. No force can be understood except by the regularity with which we witness events, and thus hoping for a complete mechanical account of causal processes is not feasible. This opens the door for action at a distance, and gives further insight into to the origin of the locality assumption.

[4] The practical application of this definition is certainly difficult depending on individual instances of action at a distance. How can one observe a mark in every case and how can one determine that a mark is relevant to the causal relationship between two events? Still, it is enough for establishing the possibility of action at a distance to show that a notion of causal order is possible without appealing to temporal order.

Part II

4. Nonlocality in quantum mechanics

In part I, I show how metaphysical worries regarding action at a distance can be overcome. Reviewing attitudes towards action at a distance throughout the history of science reveals that there is no a priori reason for rejecting it. Rather, locality is a pervasive metaphysical conviction based on mistaken intuitions: that action at a distance is not explanatory, violates causality, and is generally spooky. In chapters 2 and 3, I show that action at a distance can be reconciled with explanation and causation; it is a metaphysical possibility. In part II of my thesis, I consider an actual case which suggests the empirical reality of action at a distance: nonlocality in quantum mechanics. First, I give a brief overview of the phenomena[5]. Next, I consider two ways of interpreting quantum nonlocality that do not involve action at a distance: superluminal causation and holism. Are we better off adopting either of these theories than action at a distance?

4.1 EPR thought experiment

The Einstein, Podolsky and Rosen thought experiment was developed in a 1935 paper to show that Schrodinger's equation for micro-level dynamics (quantum mechanics) is incomplete. The popular interpretation of quantum mechanics at that time[6] assumed its completeness, and thus concluded that indeterminacy relations of certain variables actually exist.

The EPR thought experiment begins by setting out two potential contradictory conclusions: quantum mechanics is incomplete, and complementary variables cannot have simultaneous reality. A complete theory, according to EPR, is one in which every element of

[5] Much of my formulation is drawn from David Albert's *Quantum mechanics and experience* (1992).
[6] The Copenhagen interpretation, developed by Niels Bohr and Werner Heisenberg.

physical reality is accounted for in the physical theory. A quantity in a theory can be considered to correspond to reality if the value of that quantity can be predicted (by a theory) without disturbing the system. EPR set out to prove that complementary variables can indeed have simultaneous reality, although quantum mechanics is unable to provide both variables. Two further assumptions are made: separability and locality. Two particles are separable if they each have a distinct state of affairs at the time of measurement. A theory is local if a change at a location depends only on properties of things at or next to that location.

The experiment goes as follows: two particles interact, and then travel away from each other. By measuring the position of one particle at a certain time one may determine the position of the other at the same time. Additionally, because of the conservation of linear momentum, measuring the momentum of a particle will indicate the momentum of the other. Momentum and position are used as measurable quantities in the EPR experiment because they are a pair of complementary variables in quantum mechanics. Since one can take either measurement of the first particle and predict the value of the same quantity for the second particle without in any way disturbing the second particle, both quantities must already be determined. Thus, EPR conclude, momentum and position have simultaneous reality and quantum mechanics is incomplete.

4.2 Bell's theorem

John Stewart Bell developed a way to test the real-world validity of the EPR experiment (1964). Working from the assumptions of the EPR experiment, Bell derived a series of inequalities that should show up in the correspondence of measurements between the particles (contrary to the predictions of quantum mechanics) if the particles do not communicate with each other once separated. If these inequalities between the predictions of quantum mechanics and the actual measurements were not present in experimentation, then there would be no obvious way to explain the correlation between the measurements of the two particles without violating locality. Bell articulates this consequence in a theorem that states: "if [a hidden variable theory] is local it will not agree with quantum mechanics and if it agrees with quantum mechanics it will not be local" (2004, p. 65).

Experimentation later in the 20th century and early in the 21st century showed a violation of Bell's inequalities[7], confirming quantum mechanics, and invalidating the EPR thought experiment. Following the results of these experiments, locality has occupied a vulnerable position in empirical science. There is some way that particles separated by great distances (so great that no signal at or slower than the speed of light could be passed between them) communicate with one another so that one particle 'knows' how the other particle was measured. At first glance, it appears that there is instantaneous interaction between these particles: action at a distance. The prejudice against action at a distance remains, however, so considerable effort has been put into interpreting quantum mechanics so as to avoid it.

4.3 Alternative interpretations

There are three main ways to interpret quantum nonlocality: superluminal causation, holism, and nonseparability. In chapter 5, I will consider the possibility of superluminal causation. Although this suggestion is scientifically rigorous (compared to holism and nonseparability), superluminal causation contradicts relativity theory (which caps speed at the speed of light[8]) and the description of potential faster than light particles encounters severe roadblocks mathematically and conceptually.

[7] The first 'loophole-free' experimental confirmations of the violation of Bell's inequalities were performed in 2015.
[8] This is not strictly accurate, as there are ways to interpret special relativity which require only that the speed of light be invariant, not a limit. Still, serious conceptual problems arise even if superluminal causation is not necessarily in contradiction to relativity theory.

Holism was suggested by Niels Bohr in an attempt to defend the popular interpretation of quantum mechanics that he developed with Werner Heisenberg from Eintein's criticism (1935). The EPR experiment was nonsensical, Bohr claimed, because quantum mechanics could not be interpreted with the same toolset as classical mechanics. In his response to Einstein, Podolsky, and Rosen, Bohr suggested that "the apparent contradiction [revealed by the EPR experiment] in fact discloses only an essential inadequacy of the customary viewpoint of natural philosophy for a rational account of physical phenomena of the type with which we are concerned in quantum mechanics" (1935, p. 696-697). The apparent metaphysical richness of a holistic universe has proven attractive to subsequent interpreters of nonlocality, some of whom have attempted to bring more precision to the theory. In the chapter 6 I will discuss holism and nonseparability.

5. Superluminal causation

Superluminal causation is a possible interpretation of nonlocal phenomena in quantum mechanics. When Bell's inequalities are tested, photons are far enough apart to prevent signaling even at the speed of light. Any communication between photons would have to be superluminal. In this chapter I summarize the feasibility of faster than light particles. In the first section I discuss whether superluminal speeds are in direct contradiction to the theory of special relativity. In the second section I explain the paradoxes which would arise if tachyons (faster than light particles) exist. I conclude this chapter by asserting that the difficulties with and lack of evidence for tachyons make a theory which posits tachyons to explain nonlocal phenomena in quantum mechanics undesirable.

5.1 Possible contradictions between superluminal speeds and special relativity

Superluminal signaling is potentially contradictory to the theory of relativity because the speed of light is taken to be a cap above which nothing can travel without strange consequences. In Einstein's theory of special relativity (1905), the laws which are derived from the invariance of the speed of light indicate that as a frame of reference approaches the speed of light, clocks tick more slowly and distances contract (from the perspective of outside this frame of reference). If anything were to travel at a speed faster than light, the laws imply that clocks would tick backwards and lengths become negative. The general assumption is that this is nonsensical, and thus speed is capped at the speed of light.

Tim Maudlin (2011) makes the case that the above assumption (that superluminal speeds are in direct conflict with special relativity) is wrong. In fact, the only assertion about the speed of light that is integral to relativity is that it is invariant: it will remain the same regardless of the frame of reference. The consequences of faster than light particles may be unusual, but they are not impossible.

As particles accelerate, they become heavier. As it accelerates towards the speed of light, a particle's mass nears infinity, and more and more energy is required to keep it accelerating. To accelerate a particle to a speed faster than light, infinite energy would be required. This is impossible. The speed of light, then, is a speed limit for particles of lower speeds: "particles which, at some time, travel below the speed of light cannot be accelerated above that speed" (Maudlin, 2011, p. 71). Maudlin defends the possibility of particles which never exist below the speed of light, and thus are not in direct contradiction with relativity theory.

5.2 Tachyons as a solution to nonlocal phenomena

Tachyons, posited particles which travel faster than the speed of light, are not barred by special relativity, but there are counterintuitive consequences which must be addressed for their existence to be feasible. In this section I draw from Michael Kreisler's evaluation of tachyons (1973) to summarize what happens when faster than light particles are permitted. First, I discuss the characteristics of tachyons. Next, I discuss causation paradoxes that would arise were tachyons to existence and the reinterpretation principle, a potential way to resolve tachyon paradoxes and preserve causation.

Tachyons are 'born' at superluminal speeds; it is necessary that they never travel slower than the speed of light regardless of reference frame. Just as subluminal particles can never broach the speed of light according to the theory of special relativity because their mass increases indefinitely as their speed approaches c (meaning that more and more energy is required to accelerate them), tachyons become indefinitely heavier as they slow towards c. Thus, they never reach c. A difficulty remains: what would things look like from the frame of reference of the tachyon? Tim Maudlin suggests that one should leave the question of a tachyonic frame "to mystics and theologians" (2011, p. 74). This is sophistry, however. If every other reference frame is accessible to scientific enquiry, why should a faster than light reference frame be any different? Perhaps our inability to conceptualize the possibility of a faster than light reference frame indicates a serious issue with the feasibility of such a frame existing.

The rest mass of a tachyon, according to relativity theory, is imaginary. If it weren't for the tachyonic fram of reference, this could be dismissed as trivial, considering a tachyon cannot ever be at rest. In its own frame of reference, however, a tachyon is at rest; the meaning of imaginary mass must be addressed by a theory with posits tachyons. Tachyons accelerate when energy is lost (as I mentioned, a tachyon can never broach the speed of light; it would require infinite energy to slow down so much). It is possible for tachyons to have zero energy, and thus infinite speeds are possible.

Faster than light speeds in the theory of special relativity can result in backwards movement in time. Since tachyons have a velocity greater than *c*, they will be spacelike (outside the light cone in the spacetime diagram) regardless of the frame of reference. Spacelike events have no determinate time order, it depends on the frame of reference. Taking a cue from Hans Reichenbach (1958), although linear and absolute time is lost in the theory of special relativity, we are still beholden in our scientific theories to causal order. This prohibits spacelike events from having a causal relationship to a given event; only events within the past light cone of an event can be causally implicated.

Tachyons present a problem for causality because they are spacelike but can be causally connected to an event anyways. If tachyons exist, the following paradox occurs: there are two observers who can emit and absorb tachyons, A and B. A is traveling away from B at velocity *v*.

A emits a tachyon at time t and it arrives at B at time t'. B responds with another tachyon which arrives at A at time t'' In B's frame of reference, time t'' occurs after time t'. However, depending on *v*, time t'' may occur prior to t in A's frame of reference. In those cases, a particle moving faster than light would move backwards in time, and an event at t'' would be in the past light cone of an event at t (for A): A would receive a reply from B (which is supposed to be caused by A's signal) before A sent out the initial signal at time t.

One potential resolution to the above paradox is the reinterpretation principle. Since a tachyon observed as moving backwards in time would also have negative energy, the absorption of a tachyon that has traveled backwards in time can be interpreted as the emission of a new tachyon. Using the above example, instead of receiving a signal from B at time t'', A spontaneously emits a tachyon at time t''. This greatly limits the capabilities of a tachyon, however; if a tachyon were to carry any information, it could transmit information about an event at time t' to time t'', thus revealing the breach in causation and making reinterpretation impossible.

For this reason, tachyons most likely cannot be used to solve the nonlocality mystery in quantum mechanics. To explain quantum nonlocality, a tachyon would need to communicate information from the measured particle (about what measurement was taken) to its entangled other. This information would carry with it a causal mark, and in some frames of reference the unmeasured particle would 'know' what measurement was taken of its entangled other before the measurement happened. It would not be possible to apply the reinterpretation principle to salvage causality in this case, because of the information carried by the tachyon of the measurement event (Maudlin, 2011).

Maudlin suggests that if we want to use tachyons to explain quantum correlations we must either allow for backwards causation or violate the principle of relativity and allow for a privileged frame of reference. The first option leads to paradoxes: how could one possibly give a causal description of going back in time to kill one's own mother before one was born? The second option initially appeals to experience. As Maudlin points out, if there is a frame of reference in which we can preserve causal order, why not elevate it to a privileged position? He provocatively claims that "if Nature transacts her business in one coordinate frame rather than any other, the Principle of Relativity is more illusion than insight" (2011, p. 80). However, throwing out an established scientific theory to accommodate a purely hypothetical particle seems unwise, to say the least.

Although the physical possibility of faster than light particles has obviously not been exhaustively examined in the above chapter, a rough sketch of how tachyons would work is enough to show that relativistic tachyons result in counterintuitive phenomena and would require theoretical compromise. On top of this, there is almost no empirical evidence that these particles exist. An interpretation of quantum mechanics which explains nonlocality using tachyons would be entirely ad hoc.

Relativistic tachyons have properties which are incomprehensible and possibly meaningless: negative energy, the ability to move back in time, and imaginary variables. These consequences are much more difficult to conceptualize than action at a distance; action at distance has the advantage of being simple. Action at a distance is instantaneous, so it is unaffected by reference frame changes, and causality is preserved within special relativity theory. More compromises are made when tachyons are posited than when action at a distance is.

Superluminal causation is not a feasible explanation for nonlocal phenomena in quantum mechanics.

6. Holism and nonseparability

In this chapter I will evaluate holism and nonseparability. First, I consider David Bohm's interpretation of quantum mechanics. He is one of the most notorious proponents of a holistic interpretation of quantum phenomena. Bohm's formulation of holism is lengthy and lacks formality, so for the remainder of the chapter I draw from the defenses of holism put forth by Paul Teller (1986) and Richard Healey (1991). I conclude that holism and nonseparability do not offer any advantages to action at a distance as an interpretation of quantum nonlocality.

6.1 Origins of a holistic interpretation

To preserve determinacy for micro entities described by quantum mechanics, David Bohm developed an interpretation of Schrodinger's equation which regards the quantum wave to be a field acting upon a particle as opposed to a description of the probability of a particle being measured at a given point (1952). This is a hidden variable theory: the variables which are not provided by quantum mechanics are assumed to be determined but not revealed. Bohm's theory is nonlocal. As exhibited by the EPR experiment, entangled particles can change instantly depending on what happens to the other particle.

In Bohm's original paper, his proposed interpretation of quantum mechanics is explicitly not holistic (Silvio Chibeni, 2004). As Chibeni emphasizes, Bohm explains instantaneous changes among particles by positing 'quantum forces', not holistic relations between particles. Quantum forces are analogous to classical forces but not well understood. Were such forces to exist, this would not indicate any sort of fundamental interconnectedness or holistic structure, just the action of one particle on another instantiated by a fundamental force. Chibeni notes that "the fact that in certain cases these properties may undergo instantaneous changes as a result of remote actions does not seem to justify the usual claim that it introduces a 'holistic' worldview" (2004, p. 10-11).

Later in his career, however, Bohm defends a far more philosophically ambitious holistic view. Bohm suggests that there is an implicate and explicate order to reality (1980). Quantum nonlocality is viewed as a result of implicate pre-space, an interconnected holistic foundation for the divisibility that is apparent on the macro-level. Bohm eventually uses this notion of implicate order to support a theory of consciousness. He claims that "ultimately, the entire universe (with all its 'particles', including those constituting human beings, their laboratories, observing instruments, etc.) has to be understood as a single undivided whole, in which analysis into separately and independently existent parts has no fundamental status" (1980, p. 221).

Claims made in this grandiose fashion are too obtuse to offer special insight into how a particular phenomenon in science (such as nonlocality in quantum mechanics) should be understood within current scientific framework. How exactly implicate order manifests as explicate order, for example, is not and perhaps cannot be touched upon within this theory. For this reason, I do not consider this formulation of holism useful to my project, although Bohm's holism is relevant to the work of others who try and formulate a more rigorous form.

6.2 Non-trivial definitions of holism

Holism must be an ontological claim that is different from what is already considered true to justify positing it as an interpretation of quantum mechanics that explains nonlocality. Formulations of holism which restate commonly held scientific beliefs are purely rhetorical and have no explanatory power[9]. Metaphysical holism is formulated by Healey initially as "the view

[9] For example, defining holism as the belief that there are emergent properties which are not instantiated by the individual parts of a system. Emergent properties are widely accepted, and do not indicate a fundamental metaphysical shift.

that the whole is more than the sum of its parts" (1991, p. 394). Healey points out that this is both trivially true and trivially false, depending on whether one considers the composition relation among the parts to be a relation *of* the parts or a relation *over and above* the parts. A nontrivial definition of holism is necessary if one expects holism to explain phenomena like quantum nonlocality.

Holism implies a shift from analytic reduction (in which parts are successfully isolated so as to be analyzed individually) to the impossibility of such reduction. To get a grasp on what precisely holism means, one must articulate why it is that parts cannot be analyzed separately. Paul Teller offers up a definition of holism he labels relational holism (1986). Relational holism is when an individual has some relational properties which do not supervene on the non-relational properties of an individual. Teller suggests that relationally holistic individuals have 'inherent relations' with other individuals: "relations which do not supervene on the non-relational properties of the distinct individuals" (1986, p. 73). For clarity, I will formalize Teller's definition of relational holism (which he believes to be exhibited in quantum phenomena).

> *Relational Holism:* An individual w consisting of non-relational properties P(w) exhibits relational property R which is over and above P(w).

By Teller's account, the existence of inherent relations between individuals is the holistic quality which explains why parts cannot be analyzed separately.

Teller's formulation is lacking in examples and in clarity. Richard Healey's 1991 discussion of holism and nonseparability is both more accessible and more detailed. Healey sets out 'pure physical holism' as contradictory to 'pure physical particularism':

> "*Pure physical particularism:* Every qualitative, intrinsic physical property and relation of a set of physical objects from any domain *D* subject only to processes of type *P* is supervenient upon the qualitative intrinsic physical properties and relations of their basic physical parts (relative to *D* and *P*).
>
> *Pure physical holism:* There is some set of physical objects from a domain *D* subject only to processes of type *P*, not all of whose qualitative, intrinsic physical properties and relations are supervenient upon the qualitative, intrinsic physical properties and relations of their basic physical parts (relative to *D* and *P*)." (Healey, 1991, p. 402)

Most scientific explanations can serve as an example of pure physical particularism: the momentum of a billiard ball is supervenient upon its mass and velocity. Healey admits that there is no easy example of pure physical holism. His hope is that quantum mechanics may serve as an example. This is suspicious: if there is not even an abstract example of a concept which can be given in order to illustrate it, is it meaningful?

Moving forward, I will accept Healey's definition of pure physical holism as adequately novel and nontrivial. In the next section I will discuss the distinction Healey makes between holism and nonseparability.

6.3 How to differentiate between holism and nonseparability

Healey attempts to delineate holism from nonseparability. His discussion is clearly influenced by Einstein's formulation of locality and separability, but I believe he misses the mark if he meant to preserve Einstein's original conception. Nonseparability in Healey's sense is still of interest, however.

Einstein, in his argument for the incompleteness of quantum mechanics, differentiates between locality and separability (Don Howard, 1985). Separability is the principle that "any two spatially separated systems possess their own separate real states" (Howard, 1985, p. 173); locality has to do with how action is propagated between distinct systems. Healey treats separability as the equivalent of locality: "if spatiotemporal separability holds, then every physical process is determined by what happens locally" (1991, p. 406)[10]. Although I would argue along with Howard that this is not what Einstein had in mind, nonseparability in this sense is fruitful for my purposes because it is equivalent to action at a distance. Healey admits as such when he says that the motivation for preserving separability in scientific theories is to avoid action at a distance (1991, p. 407).

Initially, Healey insists that holism and nonseparability are entirely distinct ideas. He unconvincingly claims that "holism has to do with the irreducibility of certain part-whole relations, while nonseparability is to be understood in spatiotemporal terms" (1991, p. 408). This is a vague way of framing the difference. Pure physical holism, as Healey defines it, has an implicit reference to spatiotemporality. If holism is to be understood in terms of processes, one must assume a spatiotemporal element.

Healey reformulates his definitions of separability and holism to protect against objections, and ends up basically consolidating the two ideas. His second definitions are as follows:

[10] The confusion here points to a larger problem in the literature about holism, nonseparability, and nonlocality. There is no consensus as to how each concept is different from the next. Bohm and Bohr developed holistic theories in response to nonlocality: that is, more in the sense that Healey is using nonseparability here. On the other hand, Teller and Healey are motivated in their formulations of holism to account for not just nonlocality in quantum mechanics, but indeterminacy relations as well. The subject of this paper is action at a distance, and for that reason I will disregard the implications of holism on indeterminacy relations and focus on how (or if) holism can provide an explanation of quantum nonlocality that is different from and preferable to action at a distance.

"*Pure spatial holism*: There is some set of physical objects from a domain *D* subject only to processes of type *P*, not all of whose qualitative, intrinsic physical properties and relations are supervenient upon the qualitative, intrinsic physical properties and the spatial relations of their basic physical parts (relative to *D* and *P*).

Spatial nonseparability: There exists a compound physical system, not all of whose qualitative, intrinsic physical properties supervene on the qualitative, intrinsic physical properties of its spatially separated component systems together with the spatial relations among these component systems." (Healey, 1991, p. 412)

Healey admits that one could easily take holism and nonseparablity to be equivalent, given these definitions (1991, p. 412). A set of physical objects from a domain *D* is equivalent to a compound physical system. Basic physical parts are equivalent to spatially separated component systems. In the following section I criticize Healey's account of holism and nonseparability and defend an objection that Healey replies to.

6.4 Criticism of Healey

Healey is motivated to reformulate his definition of holism in spatial terms to defend against the following objection: there is an object *w* made up of physical parts *P(w)*. There is a property *J* which *w* possesses which is 'nonessential and intrinsic'. *J* does not supervene upon *P(w)*. However, there is a relation *R* which holds among *P(w)*only if *w* possesses the property *J*. Because *R* is a relation between the parts, it may be considered a part of the supervenience basis, and thus whenever *J* is present in *w* it is supervenient upon *R*: there is no holism (Healey, 1991).

To counter this objection, Healey replaces 'relation' with 'spatial relation'. His reasoning is that "other intrinsic relations supervene on spatial relations" (1991, p. 409). Healey gives the example of gravity to illustrate his point. I find this entirely unconvincing. The spatial relation between two masses engaging in a gravitational relation is secondary to gravitational force itself, that which determines the nature of the action that the two masses undergo. Spatial relations are not prior to laws which determine how a relation will play out. If one were to describe the gravitational relation between two objects, it is not enough to simply give the spatial relation. Gravitational relation only becomes meaningful when the natural law which determines the action of gravity is known. I don't consider his claim that *R* cannot be a spatial relation and thus cannot be included in the supervenience basis a convincing response to the above objection.

Healey discusses electrostatic attraction between charged particles as another example of an intrinsic relation which is not spatial, but which can be reduced to a spatial relation: he claims that electrostatic attraction "depend[s] on the spatial distance between the particles as well as on their individual electric charges" (1991, p. 403). Again, this seems to oversimplify the relation so much as to render it unrecognizable. There is no justification for prioritizing the distance between the particles over the laws which govern the interaction between the electric charges.

A significant difficulty with Healey's definitions is that he does not explicate his terminology or give examples. He admits that no example can be given to illustrate his formulation of holism, but suggests that quantum phenomena may be utilized for this purpose (1991, p. 402). This is circular, however; the goal of his paper is to clarify the concept of holism and then see if quantum phenomena are an instance of this concept. When he suggests that the concept is unclear but could be clarified by quantum phenomena, he turns the purpose on its head and runs the risk of developing an ad hoc notion of holism designed to reflect quantum phenomena.

6.5 Comparison of holism to action at a distance

In this section, I will consider whether holism (as Healey and Teller have formulated it) is genuinely different than action at a distance and whether it is preferable.

Pure spatial holism can be reduced to spatial nonseparability, and nonseparability can be reduced to action at a distance. Healey's formulations of holism are all descriptive of merely action at a distance. Holism is present in phenomena in which one cannot give an account of relations (or properties) of a system which appeals to the physical properties and relations of the parts of that system. In other words, when there is no mechanical model of that system. Healey has simply restated that we do not consider explanations that do not conform to our mechanical convictions about the world as truly explanatory[11] and applied the label of holism to action at a distance. His theory of holism adds nothing new to action at a distance and has no explanatory power. Healey seems to rely on the mystical implications of holism without cashing out how a holistic interpretation could (1) provide a more satisfying explanation of quantum phenomena or (2) prove fruitful for metaphysics.

Teller attempts, in his theory, to provide an additional explanatory component: inherent relations (1986). The term is essentially meaningless, however, and there is no way forward to access and investigate these mysterious relations. Bohm's original suggestion (1952), that there may be quantum forces which propagate differently than classical forces, is more promising. Instead of positing something metaphysically weighty like holism (which seems a bit like throwing the baby out with the bath water) why not posit quantum forces which act a distance? This method preserves an analogy between classical and quantum physics while better reflecting how we perceive the world to be. Objects and systems do not act indiscriminately upon each

[11] I have discussed this in detail in chapters 1- 3.

other as if a part of a “deeply intermeshed web” (Teller, 1986, p. 80) but rather with regularity and according to laws, both in everyday experience and within our scientific theories.

Conclusion

If there is empirical evidence indicating action at a distance, one should posit a theory that appeals to it. I have shown that there is no a priori justification for assuming locality, and that action at a distance can effectively explain causal relations within science (if one adheres to a regularity theory of causation). Furthermore, I have considered quantum nonlocality and found explanations which attempt to account for the phenomena by means other than action at a distance to be insurmountably conceptually implausible (superluminal causation), or simply lacking in meaning (holism). Action at a distance is simple, hypothesizes no unobserved mechanisms, and saves the appearances of quantum nonlocality (as it is currently understood). There is no reason, then, that action at a distance should not be considered as an explanation for quantum nonlocality.

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