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Rhetoric and metaphor in the emergence of modern physics

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Rhetoric and metaphor in the emergence of modern physics

by

Richard David Johnson

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Rhetoric and metaphor in the emergence of modern physics

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This dissertation offers a series of rhetorical analyses of the seminal papers of the quantum theory. Specifically, it discusses the central role that metaphors play in the invention of new scientific arguments that form the basis of schools of scientific thought. The theory of metaphor that is developed for analysis is situated into the tradition of the rhetoric of the “older” sophists of ancient Greece. Metaphor, or more accurately ‘trope,’ was a constitutive feature of sophistic beliefs about language and rhetoric. Applied to scientific texts, the sophistic understanding of metaphor illustrates how scientific beliefs can be brought into contrast, leading to conceptual changes in scientific communities. The study applies metaphorical analysis to three different papers from quantum theory. First, it analyzes Max Planck’s original 1900 quantum paper, “On the Theory of the Energy Distribution Law of the Normal Spectrum,” showing how his use of another metaphor leads to the unexpected emergence of the quantum postulate as a new metaphor. Second, it analyzes Albert Einstein’s 1905 light quanta paper, “Concerning a Heuristic Point of View about the Creation and Transformation of Light,” showing how new scientific metaphors, like the quantum postulate, urge other scientists to change their perspective and adopt a new understanding of reality. Finally, it analyzes Niels Bohr’s 1927 Copenhagen interpretation paper, “The Quantum Postulate and the Recent Development of Atomic Theory,” showing how the quantum postulate leads to a new world view for modern physics.

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CHAPTER ONE QUANTUM THEORY AND RHETORIC

Our task is not to penetrate into the essence of things, the meaning of which we don't know anyway, but rather to develop concepts which allow us to talk in a productive way about phenomena in nature.

Niels Bohr

The discipline of physics in the twentieth century is defined by the development of two theoretical narratives that dramatically changed the way scientists interpret nature. The first is the theory of relativity. The second is the quantum theory. Of these two narratives, the quantum theory, especially “quantum mechanics,” is far more revolutionary in scope.¹ Undoubtedly, the theory of relativity dramatically changed physicists’ understandings of time, space, and movement, but in many ways Einstein’s notion of a relativistic universe represented the final summit of classical physics with its reliance on notions of causality, certainty, and objectivity. In contrast, quantum mechanics undermined much of the core of physics by abandoning cherished notions of causality, certainty, and objectivity that had been unquestioned pillars of physics since Newton. With the evolution of the quantum theory in the first quarter of the twentieth century, the physics community underwent a dramatic change in beliefs about nature. This period marks the transition from what is commonly called “classical physics” to “modern physics.”

Though few would deny that the physics community experienced an important change in beliefs in the first quarter of the twentieth century, historians, philosophers, and sociologists tend to disagree about how such large-scale conceptual changes in the body of scientific beliefs can be interpreted or explained. One of the first comprehensive attempts at such an explanation, Thomas Kuhn’s *The Structure of*

¹ J.C. Polkinghorne, *The Quantum World* (Princeton: Princeton UP, 1984) ix.

Scientific Revolutions, introduced many scholars to the notion that scientific revolutions are periods in which the members of scientific communities dramatically change the way they conceive of reality. Kuhn writes

What are scientific revolutions, and what is their function in scientific development?... scientific revolutions are here taken to be those non-cumulative developmental episodes in which an older paradigm is replaced in whole or in part by an incompatible new one.”²

Although Kuhn’s theories have been disputed on many fronts, especially by philosophers, his notion that the history of science is not progressive has had a lasting impact on numerous fields. Indeed, the terms *paradigm* and *revolution* on which he attempted to confer formalized meanings have been worn smooth with usage.

In the aftermath of the debates over Kuhn’s book, however, we find ourselves still laboring to explain these periods of “revolution” in science. They seem to be periods of great conceptual change and intellectual creativity in which the members of the physics community begin to regard natural phenomena in new ways. Moreover, these transitions between theoretical perspectives, as Kuhn points out, seem to be heavily reliant on scientists’ use of persuasion, as factions within the scientific community argue for conceptually different descriptions of nature.³ Kuhn claims that “When paradigms enter, as they must, into a debate about paradigm choice, their role is necessarily circular . . . the status of the circular argument is only that of persuasion.”⁴ By acknowledging the importance of persuasion in scientific change and advocacy, scholars like Kuhn, who research science and scientists, stress the cultural and social

² Thomas Kuhn, *The Structure of Scientific Revolutions*, 2 ed. (Chicago: U of Chicago P, 1970) 92.

³ Kuhn, *The Structure of Scientific Revolutions* 94.

⁴ Kuhn, *The Structure of Scientific Revolutions* 94.

aspects of the development of scientific theories. They also intensify the importance of argumentation, or rhetoric, as an important means of conceptual change in science.

Marcello Pera stresses this important relationship between scientific theories and rhetoric when he claims,

scientific discourse is not rhetorical in an ornamental way, as if scientific claims could be proved on certain grounds and made appealing or palatable on others. Scientific discourse is rhetorical in a constitutive way, because scientific claims are accepted only if they persuade the audience (community) within which they are put forward and debated through an exchange of arguments and counterarguments.⁵

Stressing this “rhetorical” nature of scientific discourse, in this study I will use concepts from rhetorical theory to analyze the period of comprehensive conceptual change that occurred between the appearance of the quantum hypothesis in 1900 and the introduction of the “Copenhagen Interpretation” of the quantum theory in 1927. These years mark the emergence and maturation of quantum mechanics as a new interpretation of natural phenomena—one that guides much of the current research in modern physics. The period between 1900 and 1927 encompassed one of the most vigorous theoretical periods in the history of Western physics, leaving the field of physics thoroughly changed. However, in this study these years will not be used as boundaries that rope off the beginning and completion of a new science (or paradigm for that matter); rather they are significant milestones in the evolution of scientific thought. This period of conceptual change in physics between 1900 and 1927 is especially interesting because we witness a drastic transformation in the *perspective* from which scientists interpret natural phenomena.

⁵ Marcello Pera, *The Discourses of Science*, Trans. C. Botsford (Chicago: U of Chicago P, 1994) viii-ix.

In this study, I will discuss scientific change in terms of rhetorical “invention,” illustrating how the development and advocacy of new scientific arguments formed the basis of the transition from classical mechanics to quantum mechanics. Starting with Max Planck’s 1900 paper in which the quantum hypothesis was introduced, I will show how the quantum theory originated in the form of a *metaphor* that challenged the theoretical basis of classical physics. Then, by studying Einstein’s 1905 paper on quantized light, I will show how Einstein’s interpretation of Planck’s quantum metaphor shifted Einstein’s perspective toward the phenomenon of light, urging him to reinvent previous “knowns” into new forms that were consistent with Planck’s notion of “energy quanta.” Finally, I will offer a rhetorical analysis of Bohr’s 1927 paper in which the Copenhagen interpretation was introduced. I will illustrate how Bohr consummated a new theoretical perspective by linking dominant metaphors from the quantum theory together and then “renouncing” classical understandings of objectivity, causality, and certainty as tenets of physics. I believe these papers collectively offer an excellent example of the way in which metaphors are used to invent new scientific beliefs in a community that is often resistant to them. They also show how these new metaphors, often against the wishes of their creators, urge scientists to change or abandon their entrenched beliefs about nature, leading to large scale conceptual changes in scientific communities.

My purpose in this study, therefore, is to offer rhetorical analyses of the seminal papers of quantum theory, illuminating how the new scientific metaphors they engendered formed the basis of their rhetorical invention. Indeed, I believe the following analyses of the metaphors in these texts dramatically illustrate how new scientific metaphors urge physicists to interpret their physical and social situations from quite different perspectives, thus leading to the invention of arguments that suggest new ways of conceiving reality. Toward this purpose, in chapter two, I will develop an

understanding of scientific metaphors that is designed to illuminate the usage of metaphors by physicists to invent scientific texts. Then, in chapters three through five, I will apply a metaphor-based rhetorical analysis methodology to the texts of Planck, Einstein, and Bohr, showing how each of these authors introduced new metaphors to the physics community by using these metaphors to invent arguments that urged dramatic changes in scientific beliefs. My purpose, however, is not to explain *why* scientific communities experience these dramatic changes in beliefs; rather, it is to develop a means of analysis that allows us to talk about these changes in a productive way.

I believe the field “rhetoric of science” offers a setting for this type of analysis. To generalize, rhetoric of science studies the use of discourse to develop, advocate, and change beliefs in the scientific community. As field of study, rhetoric of science is quite young, having emerged in the last half of the twentieth century. According to Alan Gross, “The rhetoric of science discipline was born late because a persistent dream of the West died hard: the dream of certain truth concerning an independent reality.”⁶ Indeed, this “dream of certain truth” has probably encouraged the disciplines of rhetoric and science to maintain a distanced if not antagonistic relationship toward one another. I believe Jean Dietz Moss is correct when she writes, “Ironically, one of the reasons for the decline of the academic discipline [rhetoric] appears to be the simultaneous rise of interest in experimental science and the desire of scientists to prevent the incursion of rhetoric into the ‘objective’ communications of its findings.”⁷ More recently, though, reconsideration in the twentieth century concerning the ability of science to discover a certain or universal truth has opened breathing space for studies of science that adopt a

⁶ Alan Gross, “The Origin of Species: Evolutionary Taxonomy as an Example of the Rhetoric of Science,” *The Rhetorical Turn*, ed. H. Simons (Chicago: U of Chicago P, 1990): 91.

⁷ Jean Dietz Moss, *Novelties in the Heavens* (Chicago: U of Chicago P, 1993) viii.

“rhetorical perspective.”⁸ Lawrence Prelli suggests that the development of rhetoric of science as a field is important because “apodictic proofs are rare, even in science, . . . concepts associated with formal logic are insufficient to describe the activities of ‘doing science.’”⁹ He suggests that rhetoric can help us understand how scientists create and evaluate scientific discourse. Similarly, Gross states that “As rhetoricians, we study the world as meant by science.”¹⁰ He argues that rhetoric “reveals” science as just another “intellectual enterprise” like other disciplines such as philosophy, history, criticism, and rhetoric itself. In other words, according to Gross, rhetoric shows that science is not a privileged route to truth or knowledge. Instead, rhetoric offers us insight into how scientists invent arguments and use symbols to construct their conceptions of reality.¹¹

R. Allen Harris claims that “rhetoric of science is the study of suasion in the interpretation of nature.” He points out that scientists use persuasion to influence one another about interpretations of nature. Therefore, rhetoric, as a discipline that studies discourse, is suited to analyzing scientists’ use of persuasion to change the beliefs of the scientific community.¹²

In every sense, however, rhetoric offers only one more perspective from which to research and explain scientific activity.¹³ Rhetoric of science is a younger sibling to

⁸ Herbert Simons sees this recent rise of rhetoric as part of an overall academic and cultural movement. See Herbert Simons, “The Rhetoric of Inquiry as an Intellectual Movement,” *The Rhetorical Turn*, ed. H. Simons (Chicago: U of Chicago P, 1990): 1-31.

⁹ Lawrence Prelli, *A Rhetoric of Science: Inventing Scientific Discourse* (Columbia, S.C.: South Carolina UP, 1989) 1.

¹⁰ Alan Gross, *The Rhetoric of Science*, (Cambridge: Harvard UP, 1990) 4.

¹¹ Gross, *The Rhetoric of Science* 3.

¹² R. Allen Harris, “Rhetoric of Science,” *College English* 53 (1991): 284.

¹³ A few scholars like J.E. McGuire and Trevor Melia suggest that the notion of a rhetoric of science leads to subjectivism and relativism. See J. E. McGuire and Trevor Melia, “Some Cautionary Strictures on the Writing of the Rhetoric of Science,” *Rhetorica* 7 (1989): 87-100.

more established studies of science like philosophy of science, sociology of science, psychology of science, and history of science. The perspective offered by rhetoric of science, however, does not exclude or invalidate the perspectives offered by philosophy, sociology, psychology, or history. Instead, it complements their research interests. Indeed, there is a great amount of overlap among rhetoric of science and these disciplines. For example, a majority of the effort in rhetoric of science thus far has been devoted especially to “historical” issues, using rhetorical theories to illuminate the invention, arrangement, and style of important historical scientific texts.¹⁴ On a smaller scale, rhetoric of science has followed “sociological” approaches, illustrating how members of the scientific community use communication to interact and persuade one another.¹⁵ Nevertheless, rhetoric of science is distinguished from history of science, philosophy of science, sociology of science, and psychology of science by its primary focus on discourse in science. By maintaining this focus, rhetoric emphasizes the

¹⁴ For examples of historical research in rhetoric of science, see Charles Bazerman, *Shaping Written Knowledge* (Madison, Wis.: U of Wisconsin P, 1988); Peter Dear, “*Totius in verba*: Rhetoric and Authority in the Early Royal Society,” *ISIS* 76 (1985): 145-161; Alan Gross, “On the Shoulders of Giants: Seventeenth-Century Optics as an Argumentation Field,” *Quarterly Journal of Speech* 74 (1988): 1-17; Alan Gross, “The Origin of Species: Evolutionary Taxonomy as an Example of the Rhetoric of Science,” *The Rhetorical Turn*, ed. H. Simons (Chicago: U of Chicago P, 1990): 91-115; Carolyn Miller, “Kairos in the Rhetoric of Science,” *A Rhetoric of Doing*, ed. S. Witte, N. Nakadate, and R. Cherry (Carbondale, Ill.: Southern Illinois UP, 1992): 310-327; Jean Dietz Moss, *Novelties in the Heavens* (Chicago: U of Chicago P, 1993); James Paradis, “Bacon, Linnaeus, and Lavoisier: Early Language Reform in the Sciences,” *New Essays in Technical and Scientific Communication*, ed. P. V. Anderson et al. (Farmington, N.Y.: Baywood, 1983): 200-224; James Stephans, *Francis Bacon and the Style of Science* (Chicago: U of Chicago P., 1975); Kenneth Zagacki and William Keith, “Rhetoric, Topoi, and Scientific Revolutions,” *Philosophy and Rhetoric* 25 (1992): 59-78; James P. Zappen, “Francis Bacon and the Histiography of Scientific Rhetoric,” *Rhetoric Review* 8 (1989): 74-88.

¹⁵ For examples of sociological research in rhetoric of science, see Steve Fuller, *Philosophy, Rhetoric, and the End of Knowledge* (Madison: U of Wisconsin P, 1993); Bruno Latour and Steve Woolgar, *Laboratory Life: The Social Construction of Scientific Facts* (Beverly Hills: Sage, 1979); John Nelson, Allan Megill, and Donald McCloskey, eds., *The Rhetoric of the Human Sciences* (Madison: U of Wisconsin P, 1987); Greg Myers, “Texts and Knowledge Claims: The Social Construction of Two Biology Articles,” *Social Studies of English* 15 (1985): 593-630; Greg Myers, “Writing Research and the Sociology of Scientific Knowledge,” *College English* 48 (1986): 595-610.

social, human, and political discourses that are part of the development and expression of scientific beliefs.

Rhetoric

The application of rhetorical theory to scientific discourse, though, requires some preliminary explanation. In chapter two, I will discuss the rhetorical invention of scientific beliefs and arguments. Before we move into that discussion, however, the following brief review of rhetoric seems necessary, especially for readers less familiar with contemporary theories of rhetoric. After this review of rhetoric, this chapter will end with a discussion of rhetorical analysis as the operative instrument of the rhetoric of science project. This review is not intended to be a comprehensive discussion of rhetoric or the discipline of rhetoric; rather, it is an introduction to the general features of rhetoric that are important to the study in the following chapters.

Let us start out by discussing the term ‘rhetoric’ in contrast to the term ‘science.’ In popular culture, the term ‘rhetoric’ is often wielded as an accusation. It is used by politicians and pundits to suggest that others are covering up truth by employing deceptive manipulations, overly verbose displays, or excessive emotional appeals. Plato, the original detractor of rhetoric, classified it among the “sham arts of flattery” akin to cooking and cosmetics (464b8). It is this popular understanding that causes rhetoric to often be associated with words like “mere,” “just,” or “empty,” especially by someone who is attempting to discredit the beliefs of another. In stark contrast, the term ‘science’ is often regarded as synonymous with truth, rationality, and reason.¹⁶ To the general public “being scientific” means to be objective, even-handed, and methodological. So, the association of a good-term like ‘science’ with a typical evil-term like ‘rhetoric’ might seem unusual, because for many people science and rhetoric

¹⁶ Richard Rorty, *Objectivity, Relativism, and Truth* (New York: Cambridge UP, 1991) 35.

imply different motives.¹⁷ Science is assumed to be the discoverer and arbiter of certainty and knowledge, while rhetoric is perceived to be the all-too-human ornamentation and amplification of opinion. Nevertheless, like any popular stereotype or caricature, neither rhetoric nor science lives up to its reputation. Rhetoric is a complex discipline that studies all forms of human communication, not only strategies of manipulation and adornment. Science is a deeply cultural enterprise that is inescapably human. Indeed, the discipline of science is known for its passionate debates, political struggles, moments of seeming irrationality, methodological blind alleys, and wildly successful intuitions.¹⁸ It is when one recognizes the richness of both science and rhetoric as complex disciplines that the connectives between them can be productively explored.

Making a “rhetoric of science” possible, contemporary rhetoricians typically broaden the province of rhetoric by suggesting that all forms of discourse, including scientific discourse, can be interpreted from a rhetorical perspective. This broader understanding of rhetoric perhaps emerges from Kenneth Burke’s definition of humans as “symbol-using animals.”¹⁹ According to Burke, humans are defined by their ability to use symbols to interpret situations, express themselves, and alter their surroundings. He defines the function of rhetoric as “the use of language as a symbolic means of inducing cooperation in beings that by nature respond to symbols.”²⁰ Similarly, another modern rhetorician, Chaim Perelman, writes that “the new rhetoric is concerned with discourse addressed to any sort of audience. . . . The theory of argumentation,

¹⁷ The concept of “god-terms” and “evil-terms” are discussed in depth in Kenneth Burke, *A Rhetoric of Motives* (Berkeley: U of California P, 1969) 298-300.

¹⁸ Holton, *Thematic Origins of Science* 8.

¹⁹ Kenneth Burke, *Language as Symbolic Action* (Berkeley: U of California P, 1966) 3.

²⁰ Burke, *A Rhetoric of Motives* 43.

conceived of as a new rhetoric or dialectic, covers the whole range of discourse that aims at persuasion and conviction, whatever the audience addressed and whatever the subject matter.”²¹ Indeed, the use of rhetoric to bring about change plays a central role in human existence. For this reason, as Lloyd Bitzer claims, rhetoric is essentially a pragmatic feature of humanity because it “functions ultimately to produce action or change in the world. . . . In short, rhetoric is a mode of altering reality, not by the direct application of energy to objects, but by the creation of discourse which changes reality through the mediation of thought and action.”²²

In this study, rhetoric will be understood to be the use of language to interpret and shape the ever-changing social and physical situation in which individuals are inevitably immersed. In contemporary definitions of rhetoric, including the one that guides this study, it is important to recognize the intertwining of two significant themes of rhetoric: interpretation and expression.²³ Though expression has always been a definitive feature of rhetoric, the rebirth of interpretation as a function of rhetoric is the result of a twentieth century revival of ancient Greek rhetoric.²⁴ This revival restores the hermeneutic dimension to rhetoric that was trivialized during the Middle Ages, Renaissance, and Enlightenment. By recovering this hermeneutic dimension, contemporary meanings of rhetoric are close in spirit to the meanings held by the ancient Greeks. For example, Aristotle’s definition of rhetoric is “an ability, in each

²¹ Chaim Perelman, *The Realm of Rhetoric* (Notre Dame, Ind.: U of Notre Dame P, 1982) 5.

²² Lloyd Bitzer, “The Rhetorical Situation,” *Philosophy and Rhetoric* (1968): 3-4.

²³ See Simons, “The Rhetoric of Inquiry as an Intellectual Movement” 1-31.

²⁴ Gadamer identifies hermeneutics, the theory of interpretation, with rhetoric when he says “Hermeneutics may be precisely defined as the art of bringing what is said or written to speech again. What kind of art this is, then, we can learn from rhetoric.” See Hans-Georg Gadamer, *Reason in the Age of Science* (Cambridge, Mass.: MIT Press, 1992) 119.

case, to see the available means of persuasion.”²⁵ In this definition, we see the balance between interpretation and expression in Aristotle’s understanding of rhetoric. Aristotelian rhetoric stresses that speakers or writers first interpret the situation, or case (*peri hekaston*), then “see” the means of persuasion (*pisteis*), and finally express themselves appropriately in that particular context.²⁶ Indeed, *topos*, a central feature of Aristotle’s *Rhetoric*, literally meant the “place” where the rhetor could find the “available means of persuasion.”²⁷ Another quite different example of the interpretive nature of Greek rhetoric is the stress that “sophistic” rhetoricians, especially Gorgias of Leontini, placed on the presumption that speakers and writers are always in an interpretive stance.²⁸ Gorgias taught that rhetors are inescapably part of mutating situations that they must interpret rhetorically and to which they must react rhetorically.²⁹ Though their views on rhetoric differed greatly, both Aristotle and the sophists stressed the importance of interpretation in rhetoric.³⁰ It was during the Middle Ages, Renaissance, and Enlightenment that rhetoric was primarily reduced to considerations of expression.

²⁵ Aristotle, *On Rhetoric* (New York: Oxford UP, 1991) 36.

²⁶ George Kennedy offers a detailed discussion of Aristotle’s definition of rhetoric in his translation of Aristotle, *On Rhetoric* 36.

²⁷ Kennedy defines Aristotle’s understanding of topics in Aristotle, *On Rhetoric* 45.

²⁸ Scott Consigny, “The Styles of Gorgias,” *Rhetoric Society Quarterly* 22 (1992): 43-53.

²⁹ Eric Charles White, *Kaironomia: On the Will to Invent* (Ithica, N.Y.: Cornell UP, 1987) 13-15. Reflecting the interpretive nature of rhetoric, Gorgias talks about rhetoric as similar to medicine in his “Enconium to Helen.” See Gorgias, “Enconium to Helen,” *The Older Sophists*, ed. Rosamond Sprague, trans. G. Kennedy (Columbia, S.C.: University of South Carolina Press, 1972): 53. Also, in Plato’s less flattering account of Gorgias in the dialogue *Gorgias*, Gorgias makes many references to the relationship between rhetoric and medicine. These references suggest that in life he may have talked about these connections. Plato, parodying Gorgias, challenges Gorgias’ connection.

³⁰ It is important to note that rhetoric during the Middle Ages and Renaissance loses much of its interpretive quality, thus stripping away concerns about the invention of arguments in favor of prescriptive understandings of style or eloquence. See James Murphy, *Rhetoric in the Middle Ages* (Berkeley: U of California P, 1974) 42.

In large measure, the rekindled interest of the discipline of rhetoric in interpretation is important because it has re-established the primary role of *invention* in rhetoric that was of paramount concern to the ancient Greeks. Broadly defined, invention is the act of interpreting one's situation through rational means and then developing a persuasive argument that is appropriate to one's purpose in that situation. In Greek rhetoric, invention was clearly the focal point of the traditional three-part division of rhetoric: invention, style, and arrangement. Aristotle privileged invention through his quasi-logical system that stressed the usage of "artistic" (*entechnoi*) means of persuasion (*pisteis*) to develop arguments.³¹ Gorgias, even more mindful of the importance of invention than Aristotle, collapsed style and arrangement into invention, employing antithesis and narrative to create and mold arguments.³² Gorgias also drew analogies between rhetoric and fighting to suggest that speakers need to be constantly interpreting their opponents' verbal attacks while looking for the opportune moment and place to counterattack.³³ For Gorgias, as Eric White argues, rhetoric was synonymous with one's ability to invent.³⁴

The revival of the interpretive nature of rhetoric, however, has also awakened some of the debates about rhetoric that were common in ancient Greece. These debates focused on the depth to which rhetoric can be used to interpret one's context and shape one's understanding of reality. Aristotle's original answer to this debate was to enforce clear epistemological divisions that separated the disciplines of science, dialectics, and rhetoric. Some contemporary rhetorical scholars, like James Kinneavy, maintain these

³¹ White, *Kaironomia: On the Will to Invent* 29.

³² Susan Jarrett, *Rereading the Sophists* (Carbondale, Ill.: Southern Illinois UP, 1991) 27-28.

³³ Scott Consigny, "Gorgias Use of the Epideictic," *Philosophy and Rhetoric* 25 (1992): 286-287.

³⁴ White, *Kaironomia: On the Will to Invent* 29.

divisions by viewing rhetoric as a limited form of communication that is specifically concerned with intentional attempts to persuade.³⁵ These scholars argue that other forms of discourse, sometimes called “referential” discourse, are ideally non-persuasive and thus non-rhetorical.³⁶ For example, they suggest that grocery lists, logical proofs, or scientific demonstrations can be purely referential because their authors did not set out to persuade. Also, these scholars assume that ideally science and/or dialectics can develop discourse that avoids persuasion. For example, Kinneavy writes “A discourse which becomes noticeably expressive or directly persuasive or literally preoccupied is a discourse which is in danger of becoming nonscientific.”³⁷ Denying the premise that all communication must be rhetorical, Kinneavy argues that scientific discourse can achieve a “referential” status and thus be non-rhetorical, because scientific discourse is dominated by propositions that can be verified empirically or through pure logic.³⁸ Similarly, Trevor Melia attempts to guard the traditional division between rhetorical and non-rhetorical discourse when he writes,

In their disposition of philosophical issues, Kline, Munevar, and Weimer establish the *possibility*, in the most fundamental sense, for a rhetoric of science. Along with Kuhn, Feyerabend, Hanson, Polyani, Bohm, et. al., they breach the once impenetrable wall of hard science.

³⁵ James Berlin calls this approach the “objective” form of rhetorical theory. Among the objective theories, he places “current-traditional rhetoric” that dominates most of the current textbooks in English. He also classifies most revivals of classical rhetoric and cognitive rhetorics into this camp. See James Berlin, *Rhetoric and Reality* (Carbondale, Ill.: Southern Illinois UP, 1987) 180-186.

³⁶ James Kinneavy and Edwin Black offer the most definitive explanations of the limited view of rhetoric. See James Kinneavy, *A Theory of Discourse* (New York: Norton, 1971) 215-217 and Edwin Black, *Rhetorical Criticism: A Study in Method* (New York: Macmillan, 1965) 11-20. Few recent defenses of view have been made recently; however, many rhetoricians implicitly assume that such a division exists, especially between logic and rhetoric.

³⁷ Kinneavy, *A Theory of Discourse* 88.

³⁸ Kinneavy, *A Theory of Discourse* 76.

Inside these walls lies *terra incognita* for rhetoric. And no amount of debate about the work of the philosophers of science, whatever its merit, will secure scientific territory for rhetoric.³⁹

Ideally, according to this view of the limited role of rhetoric, scientific discourse only becomes “rhetorical” when considered from issues of style and arrangement. It is assumed that “facts” of science and the non-rhetorical logic or method of science are grounded in reality.⁴⁰ Therefore, at its most basic level, scientific discourse has a “recalcitrance” or “factual content” that is not open to rhetorical interpretation.⁴¹

Unlike Aristotle, the sophists believed that meaning and “truth” are created solely through interpretations and expression of one’s ever-changing social and physical situation.⁴² John Poulakos claims that the sophists were concerned with the possible, whereas Aristotle was concerned with the actual.⁴³ Also, the sophists stressed *change* while rejecting the notion of permanence that became a central feature of Western philosophy after Plato.⁴⁴ Therefore, in sophistic rhetoric there was the assumption that no “factual content” or “outside reality” exist that can be separated from

³⁹ Trevor Melia, “And Lo the Footprint . . . Selected Literature in Rhetoric and Science,” *Quarterly Journal of Speech* 70 (1984): 311.

⁴⁰ After the decline of logical positivism, few scholars would suggest that science can get at a raw form of absolute truth. Instead, like Kinneavy, they might suggest that “certainty as something to be approximated is still the ideal of scientific logic.” Kinneavy, *A Theory of Discourse* 106. Likewise Melia writes, “Without a doubt, science has offered the most hope in the continuing quest for certainty. The quest should not be too easily abandoned.” Melia, “And Lo the Footprint . . . Selected Literature in Rhetoric and Science” 312. Interestingly, quantum mechanics abandoned certainty a little over fifty years before Melia wrote this article.

⁴¹ See McGuire and Melia, “Some Cautionary Strictures on the Writing of the Rhetoric of Science” 87-100.

⁴² White, *Kaironomia: On the Will to Invent* 14-15.

⁴³ John Poulakas, “Toward a Sophistic Definition of Rhetoric,” *Philosophy and Rhetoric* 16 (1983): 44-45.

⁴⁴ Poulakas, “Toward a Sophistic Definition of Rhetoric” 45.

the discourse in which meaning and knowledge are negotiated.⁴⁵ Scott Consigny suggests that the sophists did not ground their understanding of knowledge or reality on a systematic epistemology.⁴⁶ Rather, the sophists believed that humans are “thrown into” mutating cultural, social, and physical situations in which they create and shape meaning only through contextualized interpretation and expression.⁴⁷ Consigny suggests that sophistic rhetoric is hermeneutic, or interpretive, and not epistemic. As such, sophistic rhetoric avoids the “foundationalist” or “essentialist” philosophies that are brought about by the notion of an epistemology.⁴⁸ Instead, sophistic rhetoric is interpretive in nature, viewing all discourse as open-ended. “To the hermeneutic thinker,” Consigny writes, “there is no one description of knowledge that is ‘ultimate’ or ‘final.’”⁴⁹ Instead, various descriptions are endlessly reinvented as one’s cultural, social, and physical situation changes.

Various contemporary scholars have knowingly or unknowingly picked up the mantle of the sophists. Victor Vitanza and Susan Jarrett claim that much of the recent work in postmodernism and deconstruction is appropriately classified as a part of the sophistic tradition of rhetoric.⁵⁰ Michael Leff sees the recent revival of sophistic rhetoric as a means to create unity among fields that are attempting to “push the foundationalist

⁴⁵ Consigny, “The Styles of Gorgias” 48.

⁴⁶ Consigny, “The Styles of Gorgias” 47.

⁴⁷ White, *Kaironomia: On the Will to Invent* 14-15.

⁴⁸ Consigny, “The Styles of Gorgias” 48; See also Richard Rorty, *Philosophy and the Mirror of Nature* (Princeton: Princeton UP, 1980) 315-322.

⁴⁹ Consigny, “The Styles of Gorgias” 48.

⁵⁰ Victor Vitanza, “Critical Sub/Versions of the History of Philosophical Rhetoric,” *Rhetoric Review* 6 (1987): 45. See also Jarrett, *Rereading the Sophists*.

bully off the academic block.”⁵¹ Gross, a rhetorician of science, claims that the erasure of Aristotle’s arbitrary lines between the rhetorical and the so-called “non-rhetorical” allows the “spirit of the first Sophistic to roam free.”⁵² In *Paralogic Rhetoric*, Thomas Kent fills out the relationship between postmodern rhetoric and the sophistic tradition by suggesting that sophistic rhetoric offers an alternative understanding of discourse:

An alternative to our Platonic-Aristotelian rhetorical tradition, the Sophistic tradition, provides the historical foundation for a paralogic rhetoric, a rhetoric that treats the production and analysis of discourse as open-ended hermeneutic activities and not as a codifiable system.⁵³

Discourse, therefore, is not the use of a codifiable system to transmit or approximate an “outside” truth. Rather, as Kent claims,

Because a truthful sentence cannot exist outside the language in which the statement is uttered, our knowledge of the world—knowledge constituted by assertions we take to be true about the world—cannot be something we discover “out there.” Like truth, knowledge cannot be separated from the languages we employ in our discourses about language.⁵⁴

Contemporary work in this “sophistic” tradition of rhetoric, therefore, suggest that discourse is the continuous effort to interpret one’s situation and use language to pragmatically invent arguments and express one’s beliefs.

⁵¹ Michael Leff, “Modern Sophistic and the Unity of Rhetoric,” *The Rhetoric of the Human Sciences: Language and Argument in Scholarship and Public Affairs*, ed. J. Nelson, A. Megill, and D. McCloskey (Madison: U of Wisconsin P, 1987) 34.

⁵² Gross, *The Rhetoric of Science* 3.

⁵³ Thomas Kent, *Paralogic Rhetoric* (Lewisburg: Bucknell UP, 1993) 36.

⁵⁴ Kent, *Paralogic Rhetoric* 67.

In sum, a large majority of the contemporary work in the discipline of rhetoric, including rhetoric of science, renews the Aristotelian and sophistic traditions that were initiated in ancient Greek rhetoric. Though both traditions are marked by a common interest in interpretation and invention, they offer very different conceptions of reality and rhetoric's role within that reality. The Aristotelian tradition makes clear divisions between rhetoric and an "actual" or "true" reality that does not change. For example, Aristotle writes in his *Rhetoric*,

to the degree that someone makes a better choice of the premises he will have created knowledge different from dialectic and rhetoric . . . ; for if he succeeds in hitting on first principles, the knowledge will no longer be dialectic or rhetoric but the science of which [the speaker] grasps the first principles.⁵⁵

The sophistic tradition, on the other hand, rejects these arbitrary divisions between rhetoric and the "actual" or "true." Instead, this tradition assumes that one cannot reference a certain truth that is outside of language. Rather, language is our means of interpreting and making meaning in a physical and social reality that is always changing. In the next chapter, I will explore the importance to rhetoric of science of this difference between the Aristotelian and sophistic traditions.

Rhetorical Analysis of Scientific Discourse

To claim that scientific texts are rhetorical is to open them up to analysis through rhetorical methodologies. Indeed, the analysis means of the rhetoric of science project is the use of rhetorical theory to illuminate how scientists use language to affirm their beliefs or change the beliefs of others. Much energy has been expended by rhetoricians to rope off a domain for rhetoric of science as a field.⁵⁶ But now, as the field finds itself

⁵⁵ Aristotle, *On Rhetoric* 46.

⁵⁶ Numerous articles and books titled "Rhetoric of Science" have established a base for the field by contrasting rhetoric of science to other more established fields. See Harris, "Rhetoric of Science" 282-307; Philip Wander, "The Rhetoric of Science," *Western Speech Communication* 40 (1976):

on surer footing, a majority of its effort has turned to developing analyses of scientific discourse. Through these analyses, rhetoricians highlight the way scientific discourse creates, defines, and influences scientific thought and action in a cultural, social, and physical context.

Similarities can be drawn between rhetorical analysis and what is often called “rhetorical criticism.” As Edwin Black suggests, both rhetorical analyses and rhetorical criticisms are essentially “hermeneutic endeavors” because the rhetorician is called on to interpret the text from a rhetorical perspective.⁵⁷ Nevertheless, the two are different in an important way. Rhetoricians who consider themselves “rhetorical critics” believe it is important to judge or evaluate texts when an analysis is completed. For example, Bernard Brock and Robert Scott write, “The critic judges. In some way or the other, implicitly or explicitly, he says that the rhetoric, product or process, is well done or ill.”⁵⁸ Similarly, Carroll Arnold claims that rhetorical criticism “(1) identifies significant qualities of the speaking commented on, (2) reveals criteria applied to those qualities, and so (3) offers a reasoned judgment of how fully the speaking achieved what is possible under the circumstances.”⁵⁹ Finally, Susan Foss writes, “Rhetorical criticism

226-235; Walter Weimer, “Science as Rhetorical Transaction: Toward a Nonjustificational Conception of Nature,” *Philosophy and Rhetoric* 10 (1977): 1-29; Gross, *The Rhetoric of Science*; Prelli, *A Rhetoric of Science: Inventing Scientific Discourse*. Also, the interchange between Gross and McGuire and Melia is an excellent example of how the lines of the field are being debated: see McGuire and Melia, “Some Cautionary Strictures on the Writing of the Rhetoric of Science” 87-100; Alan Gross “Rhetoric of Science without Constraints,” *Rhetorica* 9 (1991): 283-299; and J.E. McGuire and Trevor Melia, “The Rhetoric of the Radical Rhetoric of Science,” *Rhetorica* 4 (1991): 301-316.

⁵⁷ Edwin Black, *Rhetorical Questions* (Chicago: U of Chicago P, 1992) 1.

⁵⁸ Bernard Brock and Robert Scott, *Methods of Rhetoric Criticism* (Detroit: Wayne State UP, 1980) 19.

⁵⁹ Carroll Arnold, *Criticism of Oral Rhetoric* (Columbus, Oh.: Merrill, 1974) 11. One can trace this need to judge texts to the often cited seminal text of rhetorical criticism, Herbert Wicheln’s “The Literacy Criticism of Oratory” (1925). Wicheln launched the field of rhetorical criticism by arguing that rhetorical criticism, unlike literary criticism, “is not concerned with permanence, nor yet with beauty.” Instead, it is concerned with “effect.” See Herbert Wicheln’s, “The Literary Criticism of

does not stop with an interpretation of an artifact. The critic goes beyond interpretation to criticize or evaluate.”⁶⁰

A rhetorical analysis, on the other hand, is only concerned with gaining an understanding of the rhetorical features and strategies evidenced in a particular text or set of texts. Therefore, for rhetoricians of science the evaluation of scientific texts is not an important goal of their effort. Stressing analysis over criticism, rhetoricians of science rarely judge the effectiveness of scientific texts. Nor do I believe there is any privileged platform from which we might make such assessments. After all, who can really say with any confidence whether Einstein’s 1905 papers on special relativity or light quanta are “well done or ill” or if they “achieved what is possible under the circumstances.” Forsaking the evaluative component of rhetorical criticism, the purpose of rhetorical analysis is to discuss the features of discourse rather than addressing issues of why or how well. Rhetorical analyses of scientific texts attempt to show how scientists go about developing and expressing their beliefs about nature. For example, Carolyn Miller uses the rhetorical concept of *kairos* to analyze Watson and Crick’s 1954 introduction of the double-helix DNA structure;⁶¹ Gross explores the rhetorical strategies used by Newton in his *Opticks* by considering issues of arrangement, rhetorical presence, and the use of rhetorical questions;⁶² and Alex Argyros’ argues that the rise of Chaos Theory in biogenetic anthropology can be illuminated by applying

Oratory,” *Studies in Rhetoric and Public Speaking in Honor of James A. Winans*, ed. A.M. Drummond (New York: Century, 1925): 181-182.

⁶⁰ Sonja Foss, *Rhetorical Criticism* (Prospect Heights, Ill.: Waveland P, 1989) 22.

⁶¹ Miller, “Kairos in the Rhetoric of Science” 310-327.

⁶² Gross, “On the Shoulders of Giants: Seventeenth-Century Optics as an Argumentation Field” 1-17.

concepts from narrative theory.⁶³ These are only a few representative examples of a growing number of rhetorical analyses of scientific texts.

Typically, rhetorical analyses follow a few simple steps that are reflected in the organization of this study. First, they identify a text or body of texts that they will use rhetorical theory to analyze. The texts are usually selected because they are historically important, or they offer insight into the beliefs or conventions of a particular scientific community. Second, rhetorical analyses develop a framework or means for illuminating the text. A rhetorician might choose to analyze scientific texts from various comprehensive approaches, including narrative, feminism, marxism, genre theory, Burkean dramatism, metaphor, neo-classical rhetoric, among others. Each of these approaches stresses different aspects of the text. So, a marxist rhetorician and a feminist rhetorician might come to completely different, but not necessarily contradictory, interpretations of the same text. Another approach a rhetorician might choose is to focus on one or a few rhetorical concepts that can be illustrated in a scientific text. For example, Miller's analysis of Watson and Crick's DNA articles is as much or more an illustration of the rhetorical concept of *kairos* as it is an analysis of the scientific articles themselves. The final step of a rhetorical analysis is the illumination of the text. The rhetorician employs the previously defined analysis framework to the scientific texts, showing how the authors of the texts used communication to develop arguments and persuade others of their beliefs.

To conclude, the question that has plagued rhetorical analyses of scientific texts—for that matter, the field of rhetoric of science as a whole—is the depth to which rhetoric can be used to analyze the development of scientific discourse. In his book, *The Rhetoric of Science*, Gross argues that rhetorical analyses “increase our

⁶³ Alex Argyros, “Narrative and Chaos,” *New Literary History* 23 (1992): 659-673.

understanding of science, both itself and as a component of an intellectual and social climate.”⁶⁴ In other words, Gross, like many other rhetoricians of science, assumes that rhetoric can be viewed as an inherent quality of the discipline of science itself. Therefore, rhetorical analyses not only consider the style and arrangement of scientific texts, but also the activities that went into their invention as scientific discourse. Gross suggests that rhetorical analysis of scientific discourse

includes . . . features commonly construed not as rhetorical but as the discovery of scientific facts and theories. From the rhetorical point of view, scientific discovery is properly described as invention.⁶⁵

It is here where traditional rhetoricians like Melia and Kinneavy start drawing lines in the sand. Few rhetoricians would deny that the style and arrangement of scientific texts is safe territory for analysis by rhetoricians of science.⁶⁶ But some resist the implications of analyzing scientific activities, especially discovery, in terms of rhetorical invention, because claiming that scientific discourse, and thus science itself, is “invented” potentially implies a metanarrative status for rhetoric. McGuire and Melia sum up this angst:

In the meantime we do not propose to meet the obvious deficiencies of the claim that there is nothing *in the text* with the equally vulnerable riposte that there is nothing *outside of the text*. Rhetoric should not become an implausible pretender to the throne so recently and reluctantly vacated by science and its

⁶⁴ Gross, *The Rhetoric of Science* 5.

⁶⁵ Gross, *The Rhetoric of Science* 6-7.

⁶⁶ It is often remarked that the so-called “plain style” is just another rhetorical style that is designed to evoke an image of impartiality. Also, the development of the organization of the scientific article is presented in Charles Bazerman, *Shaping Written Knowledge*.

philosophy. It should, by pressing the claim of proportion rather than limits, resist the very idea of disciplinary hegemony.⁶⁷

This argument, however, is merely a red herring. A rhetorician views science as “rhetorical” through and through, just as a sociologist might consider all science “sociological” because it invariably involves social interaction. Likewise, a psychologist approaches all science as “psychological” by studying thought, and a philosopher views all science as “philosophical” because it embodies a culture’s philosophy. In other words, rhetoric offers a means of illuminating a particular side of scientific activity, namely scientific discourse, in a way that is in line with the particular interests of rhetoricians. Rhetoric of science is not—and as far as I know no one claims it is—the hegemony that McGuire and Melia fear. In this study, therefore, as a rhetorician of science I will endeavor to follow a piece of advice Bohr offered for physicists. Bohr writes,

Our task is not to penetrate into the essence of things, the meaning of which we don’t know anyway, but rather to develop concepts which allow us to talk in a productive way about phenomena in nature.⁶⁸

Likewise, in rhetoric of science, our task is not to suggest in some hegemonic way that “all is rhetorical” but rather to develop concepts through rhetorical theory that allow us to talk about scientific discourse in a productive way.

⁶⁷ McGuire and Melia, “The Rhetoric of the Radical Rhetoric of Science” 316.

⁶⁸ Niels Bohr letter to H.P.E. Hansen, 20 July 1935. Quoted in Abraham Pais, *Niels Bohr’s Times* (Oxford: Clarendon Press, 1991) 446.

CHAPTER TWO INVENTION AND METAPHOR IN SCIENTIFIC DISCOURSE

We have found a strange footprint on the shores of the unknown.
We have devised profound theories one after another, to account for
its origin. At last, we have succeeded in reconstructing the creature
that made the footprint. And lo! it is our own.

Sir Arthur Eddington

In the previous chapter, I suggested that various approaches are available that rhetoricians can use to analyze texts. Each rhetorical approach, whether it be a form of narrative theory, feminism, marxism, dramatism, neo-Aristotelian criticism, or metaphorical analysis among others, stresses different features or themes in discourse. No one approach offers a final or ultimate interpretation that cancels out the others. Rather, the various rhetorical approaches offer a plurality of descriptions of discourse, each emphasizing some features and themes of discourse while excluding others.¹

In this study, I will employ metaphorical analysis to illuminate the invention of the seminal texts of the quantum theory. Though other approaches are certainly appropriate, a study of metaphors in scientific texts, as I will show in this chapter, is especially helpful in illustrating how new concepts enter and change the beliefs of the members of the scientific community. Also, metaphorical analysis effectively highlights the interplay between change and stability in the scientific community as beliefs struggle for dominance and then eventually decline. Some metaphors, often called 'root' or 'dominant' metaphors, offer enduring perspectives through which the members of the scientific community conceptualize reality. George Lakoff and Mark Johnson call these metaphors "metaphors we live by."² Other "emergent" metaphors urge scientists to

¹ Several rhetorical critics argue that rhetorical analysis methods never lead to a final interpretation of a text; however Foss offers the clearest argument that there is no "correct" form of rhetorical interpretation. See Foss, *Rhetorical Criticism* 17.

² George Lakoff and Mark Johnson, *Metaphors We Live By* (Chicago: U of Chicago P, 1980).

change their interpretations of nature and thus conceptualize their beliefs and their situations from new points of view. Metaphorical analysis allows one to illuminate the way different metaphors in texts support stability or urge change in the scientific community.

Though metaphors often serve an “ornamental” role in texts—as they often do in poetry or fiction—in this chapter, I will show that metaphors can also serve as a *basis of invention* for scientific arguments, including description of phenomena and theories. Often, the contrasts among concepts brought about by metaphors urge scientists to embrace particular points of view from which they interpret reality and develop their theories about the behavior of natural phenomena. Also, emergent metaphors in the scientific community regularly become a source of invention for arguments that offer novel, even revolutionary, descriptions and theories for phenomena from the perspectives these new metaphors create. Kenneth Burke, I believe, correctly identifies the important role of metaphors in the invention of scientific arguments when he asks in *Permanence and Change*, “as the documents of science pile up, are we not coming to see that the whole works of scientific research, even entire *schools*, are hardly more than the patient repetition, in all its ramifications, of a fertile metaphor?”³ Indeed, though scientific metaphors are “persuasive,” even ornamental, in this study I will be particularly interested in showing how they form the basis of invention for scientific texts.

The purpose of this chapter, then, is to develop an understanding of metaphors that is suitable for discussing the use of metaphors to invent scientific arguments. Other scholars, including Max Black, Mary Hesse, Earl MacCormac, David Rothbart, Stuart Peterfreund, Mary Gerhart and Allan Russell have used theories of metaphor to discuss

³ Burke, *Permanence and Change* 95.

scientific discourse. However, this study will differ somewhat from their approaches because I will situate my discussion of scientific metaphors and rhetorical invention into the broader sophistic tradition of rhetoric. As I will show in this chapter and in the rest of this study, “sophistic” understandings of invention and metaphor are particularly useful when analyzing the highly complex and abstract arguments engendered in the texts of the quantum theory.

Invention

The assertion that metaphors play an important role in the rhetorical invention of scientific arguments, including theories, is made in various forms by scholars who study metaphors in scientific texts. For example, Arbib and Hesse argue that “all language is metaphorical,” thus allowing scientists to “construct worlds” and develop models based on “metaphoric redescription of the domain of phenomena.”⁴ Rothbart states approvingly that “many commentators . . . have accepted the metaphoric elements underlying [scientific] theory invention.”⁵ Peterfreund, discussing theories of optics, suggests that “metaphor is implicated in theory-building . . . one need only think of the wave front [of light] as a metaphor to see the kind of role that metaphor takes in theory building.”⁶ Indeed, those who have studied metaphors in science have repeatedly stressed a central role for metaphors in the way scientists conceptualize and develop descriptions of their experiences with reality.

To analyze scientific activities in terms of rhetorical invention, however, significantly changes how one views what scientists do in their offices, laboratories,

⁴ Michael Arbib and Mary Hesse, *The Construction of Reality* (Cambridge: Cambridge UP, 1986) 156-157, 170.

⁵ Daniel Rothbart, “Semantics of Metaphor and the Structure of Science,” *Philosophy of Science* 5 (1984): 610.

⁶ Stuart Peterfreund, “Scientific Models in Optics: From Metaphor to Metonym and Back,” *Journal of the History of Ideas* 55 (1994): 65.

and discussions with other scientists. Traditionally, scientific activities have been aligned with the Enlightenment notion of “discovery,” a term that, as Gross points out, is a “hidden metaphor that begs the question of the certainty of scientific knowledge.”⁷ Indeed, to discover something is to uncover it or to gain insight or knowledge about the way things *really* are. When things are discovered they are unmasked, exposed, and dis-covered. Discovery, therefore, implies that there is a definable, immutable “thing” to be laid bare⁸ and that scientists can put us in touch with fixed immutable truths that are beyond humanity (i.e. the way things really are).⁹ But, herein lies the problem. To identify a scientific claim or theory as a “discovery” one must disregard the *temporal* existence of theories and facts throughout the history of science. Did Aristotle discover that the sun orbits the earth? Did Newton discover the laws of motion? Did Einstein discover relativity? If anything, scientific theories and the “brute facts of nature” have shown a tendency toward obsolescence, not certainty. Indeed, more than anything else, the theories of Aristotle, Newton, and Einstein, seem to be the products of these scientists’ interpretations of reality, not the results of an act of finding or even approximating immutable truths. Without question, the development of these theories appropriately accorded with the physical contexts in which Aristotle, Newton, and Einstein lived; but these theories were also shaped appropriately to the social contexts in which they were advocated. The temporal nature of these contexts implies that these theories were a matter of *interpreting* the passing show rather than discovering the brute facts of nature. Moreover, the acceptance of these theories as truth by the scientific

⁷ Gross, *The Rhetoric of Science* 7.

⁸ Toulmin, *Human Understanding* 184.

⁹ Rorty discusses this assumption of Western culture in Rorty, *Objectivity, Relativism, and Truth* 35.

community were the results of effective arguments, not a revealing of the skeleton of reality.

Other disciplines like history, sociology, philosophy, and psychology that study science might offer different concepts to account for the development of scientific beliefs and arguments; but, as Gross notes, “from a rhetorical point of view, scientific discovery is properly described as invention.”¹⁰ In contrast to discovery, as Gross points out, the concept of invention in rhetorical theory better embodies the changing, contextual, uncertain, and temporal nature of scientific theories and beliefs.¹¹ If scientific arguments, including descriptions of phenomena and theories, are “invented” then their inevitable obsolescence need not be chalked up to their failure to find certainty. Rather, the eventual obsolescence of scientific theories can be viewed as a natural trait of a scientific culture that is situated within a changing physical and social context. Reinforcing this point, Herbert Simons, editor of a series of essays called *The Rhetorical Turn*, argues that this broader application of rhetorical invention to the sciences signals that “the entire process of inquiry, far from being a fully rule-bound process as the positivists had hoped or supposed, is, at all stages, underdetermined by rules; it is dependent, therefore, on individual and community judgments.”¹² Moreover, Simons points out that interpreting scientific activities as rhetorical invention stresses that inquiry and the advocacy of beliefs are more or less the same activity because scientists design their inquiries according to research questions they want to answer and arguments they wish to develop, support, or undermine.¹³

¹⁰ Gross, *The Rhetoric of Science* 7.

¹¹ This point is also made by Gross and Prelli. See Gross, *The Rhetoric of Science* 7; and Prelli, *A Rhetoric of Science: Inventing Scientific Discourse* .

¹² Simons, “The Rhetoric of Inquiry as an Intellectual Movement” 2.

¹³ Simons, “The Rhetoric of Inquiry as an Intellectual Movement” 4.

Various understandings of invention are available, but rhetorical invention invariably refers to one's *interpretive* effort toward developing an argument that is appropriate to a particular physical and social context. Karen Burke LeFevre suggests that "the act of inventing... relates to the process of inquiry, to creativity, to poetic and aesthetic invention."¹⁴ Therefore, to suggest that scientific beliefs are invented rather than found implies that scientists are not discovering the immutable brute facts of nature. Rather, such an assertion suggests that they invent their explanations and descriptions in order to come to terms with their experiences in a changing physical and social reality. To view scientific inquiry as invention stresses that the purpose and result of scientific inquiry is to use various invention strategies to interpret natural phenomena within a broader social context and then develop arguments that advocate particular scientific beliefs. Indeed, I believe in most cases, invention, more than discovery, reflects what scientists are doing in their offices, laboratories, and discussions with other scientists. When inventing descriptions of phenomena or theories, scientists interpret their changing physical and social situations to (1) identify what issues are available for inquiry, (2) discriminate among the possible courses of actions that would lead to successful explanations or arguments, and (3) determine appropriate ways to argue for their interpretations for scientific or lay audiences. This process seems more a matter of inventing scientific beliefs, not discovering them.

Interaction Views of Scientific Metaphors

Metaphor, as Arbib and Hesse, Rothbart, and Peterfreund suggest, plays a vital role in the invention of scientific texts. In this study, I too will argue that metaphors are a pivotal feature in the invention of scientific arguments, including the invention of descriptions of phenomena and theories. Therefore, much of my discussion of

¹⁴ Karen LeFevre, *Invention as a Social Act* (Carbondale, Ill.: Southern Illinois UP, 1987) 3.

scientific metaphors will fall into line with the existing work of scholars who have researched the influence of metaphors in the development of science. However, my discussion will differ somewhat from the current tradition, because I do not agree with some of the prevailing assumptions about *how* scientific metaphors bring about change in the beliefs of the scientific community. So, before offering my own ideas about how scientific metaphors effect change and serve as the basis for the invention of scientific arguments, let me first review the predominant understanding of scientific metaphors.

Almost all scholars who have recently discussed the role of metaphor in scientific discourse have conformed to a variation of what is often called the “interaction” or “tension” view of metaphor. The interaction view presumes that metaphors *structure* and *systematize* the way humans conceive and talk about reality. Lakoff and Johnson explain this central “structural” and “systemic” role of metaphor in the interaction view when they claim,

We have found ... that metaphor is pervasive in everyday life, not just in the language but in thought and action. Our ordinary conceptual system, in terms of which we both think and act, is fundamentally metaphorical in nature.... Our concepts structure what we perceive, how we get around in the world, and how we relate to other people ... If we are right in suggesting that our conceptual system is largely metaphorical, then the way we think, what we experience, and what we do every day is very much a matter of metaphor.¹⁵

Originally developed by I.A. Richards, the interaction view centralized metaphor as a constitutive element in the development and expression of human understanding. Richards in 1936, first complained that “throughout the history of Rhetoric, metaphor

¹⁵ Lakoff and Johnson, *Metaphors We Live By* 3.

has been treated as a sort of happy extra trick with words.”¹⁶ Suggesting that the opposite is true, he wrote,

That metaphor is the omnipresent principle of language can be shown by mere observation. We cannot get through three sentences of ordinary fluid discourse without it our pretense to do without metaphor is never more than a bluff waiting to be called.¹⁷

According to Richards, a metaphor comes about when “we have two thoughts of different things active together and supported by a single word, or phrase, whose meaning is a result of their interaction.”¹⁸ He explained that the meanings associated with the first part of the metaphor (the tenor) are altered by the meanings associated with the second term (the vehicle). For example, in Richards' scheme for metaphor, the simple metaphor ‘thought is light’ is believed to cause a hearer or reader to consider the meaning of the tenor (thought) through meanings associated with the vehicle (light). Richards claimed that the meanings of both words then “interact” in a way that creates a unique meaning for the metaphorical phrase.¹⁹

Metaphorical interaction between concepts, Richards argued, is a central feature in the way human conceptualize reality because, “*Thought* is metaphoric, and proceeds by comparison, and metaphors of language derive therefrom.”²⁰ For example, to illustrate Richards' notion of the pervasive influence of metaphor in human understanding, consider the metaphorical relationship between ‘thought’ and ‘light’ in

¹⁶ I.A. Richards, *The Philosophy of Rhetoric* (London: Oxford UP, 1936) 90.

¹⁷ Richards, *The Philosophy of Rhetoric* 92.

¹⁸ Richards, *The Philosophy of Rhetoric* 93.

¹⁹ Richards, *The Philosophy of Rhetoric* 96.

²⁰ Richards, *The Philosophy of Rhetoric* 94.

Western culture. Unless we were paying attention, we probably would not discern the use of a metaphor when someone said “She is bright,” “Then, the light bulb came on,” “He enlightened me,” “She cast some light on the issue,” “Suddenly the fog lifted and I had my answer,” or “Would you highlight the main points for me?” And yet, the metaphor, ‘thought is light,’ and its related metaphorical concepts determine the way we conceptualize and discourse about human thought. The metaphor itself, according to Richards’ interaction view of metaphor, determines how humans actually conceive and talk about activities in which ‘thought’ is an important concern. Indeed, it is important to recognize that people do not merely refer to ‘thought’ in terms of ‘light.’ Rather, this metaphor in many ways defines how people understand and experience thought itself.

Decades later, Max Black refined Richards’ interaction view of metaphor by claiming that a metaphor serves as a “filter” in which the context or “frame” of the metaphor causes an elaboration of the meaning of the focal word.²¹ As such, Black suggested that a metaphor contains a special cognitive content that goes beyond the literal meanings of the words that make up the metaphor.²² Explaining how this cognitive content comes about, Black suggested that the subsidiary subject (vehicle) coupled with the primary subject (tenor) creates a tension that “imposes extension of meaning upon the focal word.”²³ For example, in Black’s understanding of metaphor, one would say that the metaphor ‘thought is light’ extends the meaning of the word ‘thought’ to accommodate meanings associated with ‘light.’ The metaphor, Black claimed, becomes a filter in which the “principal subject is ‘seen through’ the metaphorical expression” and is then “‘projected upon’ the field of the subsidiary

²¹ Max Black, *Models and Metaphors* (Ithica, N.Y.: Cornell UP, 1962) 39.

²² Black, *Models and Metaphors* 46.

²³ Black, *Models and Metaphors* 40-41.

subject.”²⁴ As a result of this interaction, Black argued, the cognitive content of the metaphor causes a semantic shift of the concepts associated with the primary subject by “organizing our view” of it through suppression of some details and emphasis of other details associated with the subsidiary subject.²⁵

One of the first thorough applications of the interaction view to scientific discourse is found in Hesse’s *Models and Analogies in Science* (1966). Hesse faithfully applies Black’s interaction view of metaphor to scientific discourse by suggesting that metaphors are used to alter scientists’ “models” of reality.²⁶ She points out that the “referent” (the aspect of reality under consideration) in the metaphor serves as Black’s primary subject (i.e. Richards’ tenor).²⁷ Illustrating how metaphors work in scientific discourse, Hesse offers the following examples: “Sound (primary system) is propagated by wave motion (taken from a secondary system)”; “Gases are collections of randomly moving massive particles”²⁸ Hesse suggests that metaphors like these are pervasive in scientific thought and discourse, and that they often cause changes in scientific beliefs that cannot be explained in logical terms. Furthering this point, she claims that because scientific discourse is essentially metaphoric, “the deductive model of scientific explanation should be modified by a view of theoretical explanation as metaphoric redescription of the domain of the explanandum.”²⁹

²⁴ Black, *Models and Metaphors* 41.

²⁵ Black, *Models and Metaphors* 41.

²⁶ Mary Hesse, *Models and Analogies in Science* (Notre Dame: U of Notre Dame P, 1966).

²⁷ Hesse, *Models and Analogies in Science* 166-167.

²⁸ Hesse, *Models and Analogies in Science* 158.

²⁹ Hesse, *Models and Analogies in Science* 157.

Hesse points out, however, that an interesting problem with the application of the interaction view of metaphor to describe phenomena is that this understanding of metaphor potentially leads to the conclusion that the referent itself (the object discussed) is changed when seen through the filter produced by the subsidiary subject.³⁰ In other words, this application of metaphor seems to suggest that the metaphor changes the physical reality it seeks to describe.³¹ For example, Hesse points out that the metaphor ‘Man is a wolf’ might suggest that Man actually changed into a wolf; yet, as Hesse explains, “Man does not in fact change because someone uses the metaphor.”³² Hesse attempts to counter this problem by suggesting that the metaphor only changes the stable “model” that approximates the referent.³³ The referent itself (i.e. the natural phenomenon), however, remains unchanged.

More recently, in collaboration with Michael Arbib, Hesse has considerably extended her understanding of the importance of metaphor in science. In *The Construction of Reality* (1986), Arbib and Hesse write,

Meaning changes, or tropes, of various kinds are, in fact, pervasive in language. They are required in the learning of language at its most elementary levels, and they are also inescapable in the expression of social and religious “constructions of reality”.... we argue for the thesis that “all language is metaphorical.”³⁴

³⁰ Hesse, *Models and Analogies in Science* 166-167.

³¹ Hesse, *Models and Analogies in Science* 167.

³² Hesse, *Models and Analogies in Science* 167.

³³ Hesse, *Models and Analogies in Science* 169-170.

³⁴ Arbib and Hesse, *The Construction of Reality* 150.

Relying on this thesis, Arbib and Hesse suggest that “scientific revolutions are, in fact, metaphoric revolutions, and theoretical explanation should be seen as metaphoric redescription of the domain of phenomena.”³⁵ They argue that new metaphors compel scientists to “see” phenomena differently, causing so-called ‘literal’ and even observational terms to “shift toward the metaphorical meaning.”³⁶ Metaphors, Arbib and Hesse claim, alter the “socially constructed” cognitive schemata to which the metaphors relate.³⁷ Moreover, Arbib and Hesse claim that metaphors which are “incompatible” with current scientific paradigms eventually become the new structural basis for scientists’ schemata or paradigms. Arbib and Hesse write,

To use Kuhnian terminology, in the development of science ... normal science seeks to reduce instability of meaning and inconsistency and to evolve logically connected theories; revolutionary science makes metaphoric leaps that are creative of new meanings and applications that may constitute genuine theoretical progress.³⁸

Therefore, metaphors in Arbib and Hesse’s understanding of science become the impetus for both stability and change because they form the structural basis of schema and paradigms while also at times undermining the predominant scientific paradigm.

Another scholar, Rothbart, also utilizes much of Black’s understanding of the interaction view of metaphors by claiming that the creation of a new scientific metaphor results in a “cognitive gain” that comes about from the interaction of two scientific concepts.³⁹ He suggests that a metaphor projects the properties of a set of literal

³⁵ Arbib and Hesse, *The Construction of Reality* 156.

³⁶ Arbib and Hesse, *The Construction of Reality* 156.

³⁷ Arbib and Hesse, *The Construction of Reality* 2.

³⁸ Arbib and Hesse, *The Construction of Reality* 157.

³⁹ Rothbart, “Semantics of Metaphor and the Structure of Science” 610.

meanings onto a subject term, addressing “some weakness within the system of concepts, the gain from metaphor is expansion of the range of possible features attributable to the subject.”⁴⁰ For example, Rothbart illustrates, when Descartes employed the metaphor “each act of human behavior is the movement of a clock,” he established a metaphor that addressed the weaknesses in the meaning of “human behavior;” then Descartes utilized the metaphor to reshape and reorganize the literal meanings associated with human behavior.⁴¹ Rothbart claims that the development of scientific beliefs through metaphoric concepts is “an essential aspect of scientific reasoning for the purpose of solving conceptual problems.”⁴² Therefore, he argues, the “structure” of science is shaped by metaphors that promote theoretical unification by drawing connections between theories that are grounded in the same “fundamental methodological and ontological precepts from their respective research traditions.”⁴³

Peterfreund also advocates Black’s interaction view of metaphor, suggesting that scientific discourse involves a continual process of transference from metaphor to metonym as the scientific community turns from revolution to normal science as Kuhn describes them.⁴⁴ Peterfreund argues that “interactive” metaphors are “transferential,” thus shifting or transferring the meaning of the primary subject. Once established, however, the scientific metaphor eventually becomes a metonym, gaining literal status as the metaphor’s figurative meaning is forgotten over time (a metonym is a reduction of a previous metaphor that substitutes for a previously literal word).⁴⁵ Peterfreund

⁴⁰ Rothbart, “Semantics of Metaphor and the Structure of Science” 611.

⁴¹ Rothbart, “Semantics of Metaphor and the Structure of Science” 607.

⁴² Rothbart, “Semantics of Metaphor and the Structure of Science” 595.

⁴³ Rothbart, “Semantics of Metaphor and the Structure of Science” 613.

⁴⁴ Stuart Peterfreund, “Scientific Models in Optics: From Metaphor to Metonym and Back” 73.

⁴⁵ Burke, *A Grammar of Motives* 503.

uses examples from studies of optics in the eighteenth and early nineteenth century to argue that a tendency of scientists to privilege the use of the 'particle' metonym (the perceived 'literal') over the use of 'wave' metaphor confined scientists to a set of beliefs that retained a 'particle' interpretation of light. In a sense, Peterfreund notes, the tendency of scientists to rely on stable metonyms—what is assumed to be the literal—leads to the normal science/revolution cycle described by Kuhn because eventually a new metaphor overcomes the stability of the older metonym and then replaces it.⁴⁶

One of the more interesting adaptations of the interaction view of metaphor to scientific discourse is found in Gerhart and Russell's *Metaphoric Process: The Creation of Scientific and Religious Understanding* (1984). Gerhart and Russell argue that creative scientists "fold ... a map of a world of meanings," thus creating a metaphor that "reforms fields of meanings themselves."⁴⁷ In science, Gerhart and Russell suggest, this map-folding results in a flash of insight. They write, "it is here that the words 'Eureka, I have it!' are spoken. At this point an 'ontological flash' occurs."⁴⁸ Then, they claim that the metaphor causes a "structural change which demands that other meanings and understandings have to be changed in the wake of the metaphor."⁴⁹

In general, the interaction view of scientific metaphors has proven to be a useful way to illuminate the importance of metaphors in the invention of scientific beliefs. My reservations about the interaction view of scientific metaphors come about, however, because I believe this view relies on erroneous assumptions about conceptual change in

⁴⁶ Peterfreund, "Scientific Models in Optics: From Metaphor to Metonym and Back" 73.

⁴⁷ Mary Gerhart and Allan Russell, *Metaphoric Process: The Creation of Scientific and Religious Understanding* (Fort Worth: Texas Christian UP, 1984) 113.

⁴⁸ Gerhart and Russell, *Metaphoric Process: The Creation of Scientific and Religious Understanding* 114.

⁴⁹ Gerhart and Russell, *Metaphoric Process: The Creation of Scientific and Religious Understanding* 119.

science. What I deny is that science and scientific metaphors work in relation to a stable paradigm, conceptual structure, model, or schema that offers a fixed framework for scientific beliefs. Moreover, I do not believe that metaphors contain special meanings, offer insights into the way things really are, or create “ontological flashes” that transcend normal scientific discourse and thus *cause* or *impel* scientific beliefs to change. Indeed, for the most part, I believe Hesse, Arbib, Rothbart, and Peterfreund are correct in their descriptions of the role and influence of metaphor in scientific discourse. Where I disagree with them is in their accounts of how conceptual change in science comes about and the way in which metaphors are used to bring about these changes. These points will be addressed in more depth later in this chapter.

Since my intention is to develop an understanding of scientific metaphors and their role in the invention of scientific arguments—not to undermine the views of others with whom I for the most part agree—my discussion from this point will build on the strengths of the existing theories of scientific metaphor while attempting to reform their weaknesses. I believe the understanding of invention and metaphor in science that emerges is more useful toward analyzing the role of metaphors in the invention of actual scientific texts.

Conceptual Change

I begin by noting that current views of scientific metaphors, including the one I will develop in this chapter, all suggest that metaphors are an important feature of conceptual change in science. Conceptual change takes place when humans, including scientists, come to understand their physical and social situation differently than they had before.⁵⁰ An interesting characteristic of conceptual change in science is that it

⁵⁰ Much of my understanding of conceptual change is in line with Toulmin’s comprehensive study of this topic in Toulmin, *Human Understanding* 41-130.

seems to occur at varying rates.⁵¹ Several historians and philosophers of science make this observation in one form or another, including Kuhn, I. Bernard Cohen, Gerald Holton, Paul Feyerabend, and Stephen Toulmin, so I will try to summarize their similar but divergent views as generally as possible at this point.

These historians claim that during some time periods, the rate of conceptual change in science is relatively gradual with scientists readily laboring within the guidelines offered by comprehensive theories that bind scientific communities together. The predominant theories themselves facilitate gradual conceptual change as scientists pose research questions and develop explanations that extend and reinforce their communities' theoretical assumptions. These periods are hardly tranquil, though, as scientists struggle among divergent interpretations that more or less follow the accepted theoretical assumptions, goals, and procedures of their scientific community. Other time periods, however, witness rapid conceptual change in science. Often called "revolutions," these periods in the history of science are marked by a sudden acceleration in the change of a scientific community's understanding of nature. Two such periods were the century-long supplanting of pre-Copernican physics with the mechanistic physics of Galileo and Newton and the twentieth century supplanting of classical physics with the quantum physics of Planck, Einstein, Bohr, and Heisenberg. During these periods, firmly established theories were challenged and then undermined by new theoretical assumptions that the old theories could not absorb.

It is often popular to refer these periods of accelerated conceptual change as "revolutionary," but this term has become problematic. Stephen Toulmin argues that identifying these periods as revolutionary promotes an inaccurate "illusion" about the

⁵¹ See Toulmin, *Human Understanding*; Kuhn, *The Structure of Scientific Revolutions*; Gerald Holton, *Thematic Origins of Scientific Thought* (Cambridge, Mass.: Harvard UP, 1988); I. Bernard Cohen, *The Birth of a New Physics* (Garden City, N.Y.: Doubleday, 1960); Paul Feyerabend, *Against Method* (Verso: New York, 1988).

history of conceptual change in science.⁵² He points out that the “revolutionary illusion” is created by the assumption that human understanding operates in reference to “some system of fixed principles” that takes the unchanging form of a “paradigm,” “conceptual scheme,” or an absolute systemic reality.⁵³ Toulmin suggests that the assumption that scientific beliefs correspond to a fixed conceptual system leads one to presume that conceptual *stability* is normal or even ideal, and that periods of pronounced conceptual change are abnormal or revolutionary. Turning the tables on the revolutionary illusion, Toulmin proposes that “intellectual flux, not intellectual immutability, is... something to be expected: any continuous, stable, or universal features to be found in men’s actual patterns of thought now become the ‘phenomena’ that calls for explanation.”⁵⁴ Indeed, Toulmin seems well aware that he is calling not only for a different way of interpreting the history of science but also for new ways of looking at science itself. He writes

We have no more reason to take immutability as self-explanatory in mental philosophy (epistemics) than we have in natural philosophy (physics), or to regard stability as more ‘natural’ or ‘intelligible’ than change. Rather, we must set out to show how a single set of factors and considerations, interacting in different ways, can be used to explain both why our ‘forms of thought and perception’—concepts, standards of rational judgement, *a priori* principles and the rest—vary rapidly in some cases, situations, and circumstances, and also how, in some cases, situations, and circumstances, they can remain unchanged.⁵⁵

⁵² Toulmin, *Human Understanding* 96.

⁵³ Toulmin, *Human Understanding* 96.

⁵⁴ Toulmin, *Human Understanding* 96.

⁵⁵ Toulmin, *Human Understanding* 98.

Toulmin's point, one that I will take to heart in this study, is that our ways of conceptualizing and discoursing about nature are always changing, just as our physical and social situations are always changing. Indeed, the idea of intellectual flux in human understanding, as Toulmin points out, seems to be corroborated by the history of science itself. After all, the history of science is more or less a narrative of conceptual change in which each theory or description maintains only a temporal existence. Even so-called "stable" or "normal" periods in science have been marked by gradual changes in scientific theories as scientists sought to better explain the workings of nature. Therefore, to posit conceptual change as the basis of human understanding is to better describe the temporal nature of science itself. It should be pointed out, however, that conceptual change does not necessarily imply conceptual progress.⁵⁶ We might, relative to a particular historical context, say that someone or an entire community progressed or moved forward; but such assessments are pertinent to those individuals' or our contexts, not to any system of fixed principles. A step forward in one context (e.g. antibiotics, DDT, the atom bomb) is perhaps a step backward in another context.

The implications of Toulmin's idea of intellectual flux, however, are far more significant than they may appear on the surface. As Toulmin recognizes, his argument that change is an integral feature of human understanding challenges what is often referred to as the objectivist, absolutist, or foundationalist tradition in Western philosophy.⁵⁷ Toulmin calls this tradition the "cult of Systematicity" and suggests that absolutists and relativists are partners in a long tradition, beginning with Socrates, that posits immutability.⁵⁸ The absolutist side of this tradition, claims Toulmin, is

⁵⁶ Toulmin recognizes that his term "evolution" might imply progress, but he, like Darwin, suggests that evolution concerns change and not progress. See Toulmin, *Human Understanding* 356.

⁵⁷ Simons, "The Rhetoric of Inquiry as an Intellectual Movement" 1-31.

⁵⁸ Toulmin, *Human Understanding* 52-53.

represented by those who attempt to “define an ‘objective’ standpoint in terms of ‘absolute’ standards of rational judgement;” the relativist side of this tradition is represented by those who challenge “any demand for a universal, objective standpoint as no longer tenable, falling back on local, temporary, or ‘relative’ standards.”⁵⁹ Though absolutists and relativists claim to be opponents, Toulmin points out that they are essentially two sides of one tradition due to their “commitment to a logical systematicity which makes absolutism and relativism appear the only logical alternatives available.”⁶⁰ Toulmin suggests that the first step away from “logical systematicity” is to reject both absolutism and relativism. By doing so, he argues, scholars are then free to discuss issues of rationality and scientific inquiry in terms of conceptual change.

But, I believe Toulmin’s abandonment of systematicity and his assumption that change is the *modus operandi* of science goes against the predominant studies on scientific metaphors that employ Richards’ and Black’s interaction view of metaphor. Usually relying on Kuhn’s understanding of paradigms and revolutions, scholars who follow the interaction view of scientific metaphors invariably suggest that scientific beliefs are grounded in a system of fixed principles like a paradigm, model, schema, or some other conceptual structure. Then, these scholars argue, scientists periodically introduce new metaphors that are irreconcilable with the predominant conceptual structure on which scientists rely, ultimately causing a “revolution” to occur. As Toulmin points out, though, this reliance on the “revolutionary illusion” suggests that change in science is somehow “abnormal” and that conceptual stability is to be expected. Therefore, if new metaphors are the instigators of these revolutions, as interaction view scholars claim, then they must be regarded as *abnormal* features of

⁵⁹ Toulmin, *Human Understanding* 53.

⁶⁰ Toulmin, *Human Understanding* 84.

scientific discourse that threaten the otherwise normal workings of science. Moreover, the interaction view implies that new metaphors must be understood as working 'outside' normal scientific discourse and thought, transcending the fixed principles that make up paradigms, models, and schemata. Indeed, in the interaction view of scientific metaphors, intellectual stability is presumed—even required—to be the norm while change and the metaphors that bring about change are the exception.

To put it concisely, the central problem with the interaction view of scientific metaphors, I believe, is that it leads its followers back into what Toulmin calls the "cult of Systematicity," offering them the usual choice between absolutism (i.e. metaphors offer "special insight" into the way things "really are") or conceptual relativism (i.e. metaphors have "special meanings" that create anomalies which are 'outside' a community's common conceptual scheme). When faced with this choice, scholars like Arbib and Hesse, Rothbart, Peterfreund, Gerhart and Russell have implicitly adopted a conceptual relativist position. In their writings, new metaphors are understood to be working in an incommensurable relationship to "normal" science because they do not fit into or are relative to the larger system of stable scientific beliefs. Meanwhile, older dominant metaphors are understood to provide a stable systemic conceptual framework that "accepted" scientific beliefs are relative to. Finally, revolutions are supposed to occur when a new metaphor which is incommensurable with the dominant paradigm replaces an older dominant metaphor, thus causing all the concepts relative to the old metaphor to change to suit the new metaphor. This conceptual relativist position stresses that reality is completely a construct of the human mind, specifically metaphors.

Of course, conceptual relativism in science has been defended by scholars like Feyerabend and to a lesser extent Kuhn.⁶¹ However, as scholars like Toulmin, Donald Davidson, and Kent have shown, conceptual relativism does not seem to adequately explain how thought and language, including scientific discourse, actually function in communities.⁶² These scholars point out that conceptual changes in beliefs never seem to occur in an either/or fashion in which whole conceptual schemes, and even partial conceptual schemes, are suddenly replaced by incommensurable new conceptual schemes. Rather, as Toulmin claims, changes in beliefs seem to be more evolutionary in nature as scientists work through many interpretations to come to terms with their changing physical and social contexts. Davidson writes, “that truth is relative to a conceptual scheme ... has not so far been shown to be anything more than the pedestrian and familiar fact that the truth of a sentence is relative to (among other things) the language to which it belongs. Instead of living in different worlds, Kuhn’s scientists may ... be only words apart.”⁶³

Indeed, once again, the compelling evidence for accepting Toulmin’s understanding of conceptual change and modification of interaction views of scientific metaphor is the history of science itself. At what point in history can one say that a complete change in paradigm or conceptual scheme occurred in the scientific community? It took the better part of a century for Copernicus’ argument that the earth goes around the sun to be broadly accepted within the scientific community. Similarly,

⁶¹ See especially Paul Feyerabend, *Farewell to Reason* (London: Verso, 1987) 19-88, 265-272.

⁶² Excellent rebuttals to the conceptual relativist position can be found in philosopher Donald Davidson’s essay “On the Very Idea of a Conceptual Scheme” and rhetorician Thomas Kent’s “On the Very Idea of an Interpretive Community.” See pages 184-198 of Donald Davidson, *Inquiries into Truth and Interpretation* (Oxford: Clarendon P, 1991); and pages 76-96 in Kent, *Paralogic Rhetoric*. I agree completely with their arguments against conceptual relativism.

⁶³ Davidson, *Truth and Interpretation* 189.

the quantum theory was ardently debated for at least thirty years before many scientists would accept it. Even today, nearly a century after the emergence of the quantum theory, philosophers and scientists still debate its implications. So, if one wants to argue that metaphors bring about conceptual change in science, one needs to account for the fact that these changes take time, even lifetimes, to settle into a more or less stable form. When viewed in terms of intellectual flux, the history of science does not support the idea that metaphors are abnormal or anomalous features of scientific discourse that cause incommensurable changes in conceptual structures like paradigms, models, or schemata. Rather, if change is the norm in science, then metaphors, as the instigators of change, are most likely an all-too-normal feature of the invention of scientific discourse, including descriptions of phenomena and theories.

Sophistic Invention

There is a way to address Toulmin's claim that conceptual change is the norm in science from a rhetorical point of view. However, we must first leave aside the notion that scientists and the metaphors they use to invent arguments are working in relation to a systemic fixed set of principles. In other words, as Toulmin suggests, we must reject the Platonic/Aristotelian tradition of "logical systematicity" that offers absolutism and relativism as our only paths for understanding scientific inquiry. Only then can we discuss the role of metaphors in inventing scientific arguments without resorting to absolutism or relativism.

Fortunately, an alternative to logical systematicity can be found in the ancient and modern "sophistic" tradition of rhetorical theory. The sophistic tradition stresses that rhetoric is by nature interpretive, or hermeneutic, making it adaptive, even expectant, of change.⁶⁴ Furthermore, sophistic rhetoric foregoes absolutist appeals to

⁶⁴ Consigny, "The Styles of Gorgias" 48.

truth and epistemology that Toulmin aligns with the cult of Systematicity; yet, it also avoids giving in to a relativist position because it denies that there exists a stable structure to which beliefs can be relative to. Indeed, unlike the Platonic/Aristotelian tradition, which assumes that an immutable Being lays hidden beneath the outward motion of reality, the sophistic tradition believes in the Hericlitean notion that change is an essential feature of knowledge and human understanding. John Poulakos echoes this understanding of the temporal nature of sophistic rhetoric when he writes that the sophists of ancient Greece assumed that “Being is not a fixed, but a continuously unfolding entity whose most notable trait is its capacity for self-manifestation and self-concealment.”⁶⁵

When used to discuss scientific discourse, sophistic rhetoric stresses the assumption that speakers—in our case scientists—are always in an interpretive relationship with nature, inventing and reinventing arguments to account for a changing physical and social reality. According to Eric White and Mario Untersteiner, the sophistic understanding of *kairos*, “the opportune time and place,” stressed the assumption that speakers are inevitably thrown into mutable and changing situations that force them to use hermeneutic strategies toward developing appropriate expressions to the situation.⁶⁶ As White points out, the sophists believed that “invention would renew itself and be transformed from moment to moment as it evolves and adapts itself to newly emergent contexts.”⁶⁷ Therefore, sophistic rhetoric assumes that speakers are always interpreting the passing show, inventing courses of action that are appropriate to

⁶⁵ John Poulakos, “Rhetoric, The Sophists, and the Possible,” *Communication Monographs* 5 (1984): 219.

⁶⁶ Mario Untersteiner, *The Sophists* (Oxford: Blackwell, 1954) 106; White, *Kaironomia: On the Will to Invent* 13-16. Gorgias’ use of the word *kairos* can be found in the Helen (“to speak the needful rightly” DK B11, 2) and the Palamedes (“out of the present necessity” DK 11a).

⁶⁷ White, *Kaironomia: On the Will to Invent* 13.

the physical and social features that make up their rhetorical situation. Another important feature of sophistic understandings of invention is the assumption that various, often antithetical, arguments are always available in any case. Protagoras' fragments, *dissoi logoi* and "impossible to contradict"—which I will discuss shortly—imply important open-ended and pluralistic qualities for the sophistic understanding of invention, because these fragments suggest that no one description of nature can legitimately close out discussion by arriving at the ultimate or final description of reality.⁶⁸ Rather, sophistic invention is often a matter of playing different arguments or concepts against each another in ways that develop new accounts of reality and new points of view from which to interpret rhetorical situations.

Of course, it must be conceded that what we know of the rhetorical theories of the "older" sophists of ancient Greece is developed from speculative interpretations of surviving fragments of their work. So, I will refrain from suggesting that we can apply the rhetoric of the older sophists toward analyzing scientific texts in some direct way. Rather, I believe we can view the Greek sophists as early inspirational members of a broader sophistic tradition that, as scholars like Jarrett, Vitanza, Leff, and Kent suggest, has re-emerged in twentieth century. As such, much of the discussion of sophistic invention and metaphor that takes up the remainder of this chapter will be filled out by writings from the "modern sophistic," including the works of scholars from Nietzsche and Burke to recent scholars like Davidson and Richard Rorty who have been advancing non-absolutist theories of thought and language. Indeed, one is working within the sophistic tradition when one recognizes that humans, including scientists, cannot remove themselves from their physical and social reality, thus denying that an objective 'outside' position can be attained. Instead, physical and social

⁶⁸ Consigny, "The Styles of Gorgias" 48.

situations are assumed to be always changing and thus humans are understood to be always in a process of interpreting their situations and ‘inventing’ ways to express their beliefs.

A sophistic understanding of rhetorical invention, therefore, offers a way of looking at scientific texts that avoids seeing them as talking about what is “probably true” about a fixed absolute or immutable reality. Meanwhile, it avoids the temptation to slip into a form of conceptual relativism in which an absolute reality is substituted with a systematic, fixed conceptual scheme like a paradigm. Instead, sophistic rhetoric encourages us to see scientific texts as opportune attempts to argue about or describe phenomena in ways that are appropriate to scientists’ and the scientific community’s physical and social experiences, knowing full well that other interpretations of reality are possible and inevitable.

Though other features of sophistic invention are available for use in analyzing scientific texts, I will limit my study by concentrating on the relationship between the sophistic understandings of metaphor and *logos* in the invention of arguments. Before discussing metaphor and *logos* in relation to scientific arguments, however, it is necessary to first clarify these concepts and their function in the sophistic tradition.

Logos

G.R. Kerferd notes that *logos* had three related meanings in ancient Greece.⁶⁹ The first meaning of *logos* concerned forms of discourse, speech, or arguments. The second meaning concerned thought, reasoning, or mental processes that allowed one to form discourse. Finally, the third meaning concerned the “area of the world, that *about* which we are able to speak, hence structural principles, formulae, natural laws and so on.” David Roochnik, echoing these meanings, suggests that *logos* could be interpreted

⁶⁹ G.B Kerferd, *The Sophistic Movement* (Cambridge: Cambridge UP, 1981) 83.

to mean “rational structure” in a way that encompassed language, thought, and reality.⁷⁰ Both Kerferd and Roochnik suggest that Greek usage of the word *logos* inevitably brought all of these meanings into play, though in specific contexts one of the three meanings seems to take precedence over the others. This caution is especially meant to ward off alignments of *logos* trivially with ‘argument.’ For the Greeks, especially the sophists, to change a person’s *logos* was to change the way they rationalized or interpreted reality itself. Therefore the use of *logos* in reference to argument usually meant that the rational structure of reality itself was being altered in some way. This deepened the power and importance of argument, the revealing or altering of *logos*, in Greek understandings of reality and language.

For Gorgias, “Speech [*logos*] is a powerful lord, which by means of the finest and most invisible body effects the finest works” (DK B11, 8).⁷¹ Indeed, Gorgias believed that an understanding of the power of *logos* was essential to the study of rhetoric because he did not believe in a truth that was beyond what a person could be persuaded to believe.⁷² As such, Charles Segal argues, Gorgias did not make a clear distinction between thought, language, and reality.⁷³ They were inevitably wrapped up in one another, supporting a broader view of reality as mutable. *Logos*, the sophists believed, is the “rational structure” on which thought, language, and reality are made meaningful for humans. The proper manipulation of *logos*, Gorgias believed, makes real changes in the audience’s interpretation of reality and thus changes their reality

⁷⁰ David Roochnik, *The Tragedy of Reason* (New York: Routledge, 1990) 25.

⁷¹ The translation I am using is Rosamond Sprague, ed., *The Older Sophists* (Columbia, S.C.: U of South Carolina P, 1972).

⁷² W. Guthrie, *The Sophists* (Cambridge: Cambridge UP, 1971) 211.

⁷³ Charles Segal, “Gorgias and the Psychology of the Logos,” *Harvard Studies in Classical Philology* 66 (1962): 107.

itself. Gorgias demonstrated his belief in the power of *logos* as a great influence over rationality when he stated, “The effect of speech [*logos*] upon the condition of the soul is comparable to the power of drugs over the nature of bodies” (DK B11, 14). He also stated that all are willingly but not forcibly made slaves under the influence of *logos* (DK 26A). In this sense, *logos* inevitably governs the way in which one interprets and rationalizes reality. For Gorgias, *logos* was the beginning of speech as well as action. He states “and the beginning would have been speech, for before any future deeds it is necessary first for there to be *logos*.” (DK B11, 6).

Throughout history, Gorgias especially has been accused of being a skeptic, nihilist, or relativist due to his views of *logos* presented in his speech *On Not-Being*. Gorgias’ argument against Being, though, can also be interpreted as a rather obvious parodic rebuttal to the Eleatic (and later Platonic and Aristotelian) notion of one static Being that rationalizes all.⁷⁴ For the Eleatics, motion and change were mere illusions due to the deception of the senses, making the acquisition of truth through the senses or language impossible. The Eleatics believed that certain knowledge was only achievable through reasoning that contemplated Being (the one *Logos*). In arguing for Being, the Eleatics claimed—quite the opposite of the sophists—that there is only one *logos* (Being) that serves as a rational, immutable, and unifying structure of reality. In *On Not-Being*, Gorgias parodies the Eleatics by showing that their arguments for Being can also be supportive of an argument for Not-Being. Gorgias asserts, “for that which we reveal is *logos*, but *logos* is not substances and existing things. Therefore we do not reveal existing things to our neighbors, but *logos*, which is something other than substances.... *logos* arises from external things impinging on us, that is, from perceptible things” (DK B3, 84-85). In making this argument, Gorgias shows the

⁷⁴ Guthrie, *The Sophists* 15.

opposite of the Eleatic position. *Logos* (reality) is not something beyond humanity; rather, *logos* is a blending of beliefs, reality, senses, and language. According to Consigny, Gorgias' *On Not-Being* suggests that

one is always within the framework of *logos*, and can never perceive 'reality' directly; for the domain of discourse permits no access to any putative domain that is posited to exist 'outside' the reality fabricated from within *logos*. In Sextus's terms, Gorgias thus abolishes the illusory "criterion" presumed to exist outside of *logos*, one that would presumably indicate which speech is true or false (3B)⁷⁵

On Not-Being, rather than implying relativism because it rejects Being, reinforces the sophistic and Hericlitean notion that reality (*logos*) is always undergoing change, or coming to be.⁷⁶ If the sophists were skeptics or nihilists, they were only skeptics of claims of the possibility of certain and immutable knowledge.⁷⁷

For the sophists, *logos* was often paradoxical and more or less subversive, leading to a pluralistic understanding of reality. This feature of their rhetoric is perhaps best observed in three of Protagoras' fragments. Together they create a comprehensive view of Protagoras' understanding of *logos*. The first, commonly called the *dissoi logoi* fragment, reads "Two *logoi* are present about every 'thing,' opposed to each other."⁷⁸ The second fragment translates "to make the weaker argument (*logos*) the stronger." Finally, the third fragment is simply "It is not possible to contradict."

⁷⁵ Scott Consigny, "Sophistic Freedom: Gorgias and the Subversion of Logos." *Pretext* 12 (1991): 228.

⁷⁶ Nietzsche offers an excellent discussion of coming to be in Friedrich Nietzsche, *Philosophy in the Tragic Age of the Greeks* (Washington: Regnery Gateway, 1962) 50-74.

⁷⁷ Guthrie, *The Sophists* 47.

⁷⁸ All three of these translations are taken from Edward Schiappa, *Protagoras and Logos* (Columbia: U of South Carolina P, 1991) 87-197.

Edward Schiappa suggests that these fragments, especially the *dissoi logoi* fragment, are an extension of the Hericlitean thesis that reality is in flux. He writes, “the two-*logoi* ... fragment can be read productively as responses to certain Eleatic theories concerning human ability to comprehend and speak correctly about ‘what is.’”⁷⁹ The fragments, especially when read together, suggest a pluralistic understanding of nature in which various accounts or descriptions are possible in any situation. As such, no one ‘final’ or ‘ultimate’ description or argument can reach closure, because no one account (*logos*) can completely refute another. Instead, various arguments are opposed to one another in weaker/stronger relationships. A dominant *logos* is assumed to be ‘the stronger’ in a given context, while other arguments, or *logoi*, take on a weaker status. To make the weaker argument stronger demonstrates the subversive nature of *logos* because the stronger argument cannot completely wipe out, or contradict, its competitors, making it always susceptible to being undermined.

Logos is a very complex concept in Greek philosophy, so a comprehensive view of it is unattainable here. However, some useful suppositions can be drawn from this small sketch of the meaning of *logos* toward developing a means rhetorical analysis. First, in sophistic rhetoric, *logos* concerns the rational structure of language, thought, and reality. Consigny summarizes this aspect of *logos*: “Because the power of *logos* is unnoticed and not coercively imposed, it exerts its repressive power pervasively and insidiously. For when a community accepts certain patterns of speaking, they deceive themselves into accepting these patterns as representing ‘reality.’”⁸⁰ Second, *logoi* can be opposed to one another, ensuring a pluralistic understanding of reality in which various accounts might be stronger than others—but

⁷⁹ Schiappa, *Protagoras and Logos* 92.

⁸⁰ Consigny, “Sophistic Freedom: Gorgias and the Subversion of Logos” 230.

none can rule others out completely and adopt the mantle of certainty. Roochnik demonstrates this feature well through a useful demonstration:

A physicist for example, when asked to give a *logos* of the human body, would do so given his own version of what constitutes a rational account. His *logos* would be composed largely in the language of mathematics and would explicate the body as a moving object in space. The biologist, when asked the same question, would present quite a different story and might use a language not nearly so mathematical. More different still would be the *logos* given by a sculptor concerned with only the body's lines of beauty and grace.

The third feature of *logos* is the notion that reality, language, and thought are always in flux. This aspect of *logos*, I believe, reflects Toulmin's claim that conceptual change is an inevitable and unavoidable feature of human understanding. Language, thought, and reality are always changing, urging humans to be continuously reinventing their beliefs to suit the changing and mutable physical and social situations in which they live.

Metaphor

Metaphor, as far as we know, was first treated in a formal way by Aristotle, so it would be inaccurate to claim that the "older" sophists of ancient Greece offer a formalized conception of 'metaphor' like that of Aristotle, Richards, or Black.⁸¹ Rather, the sophists typically employed the term *trope*, a word that meant 'turn' in ancient Greek, to characterize features of figurative language like metaphor. Later, poets and rhetoricians, among them Aristotle, divided the unified notion of tropes into 'figures of speech,' encompassing metaphor, antithesis, simile, metonym, synecdoche, allegory, irony, personification, among many others. The sophists, however, did not appear to make these sorts of divisions, using tropes generously in their speeches without calling

⁸¹ Ricoeur attributes both our formal notions of metaphor and rhetoric to Aristotle. See Paul Ricoeur, *The Rule of Metaphor* (Toronto: U of Toronto P, 1977) 9-10.

attention to any differences among them. Gorgias was especially notorious for his use of tropes to play contrasting elements of words and phrases off one another in unexpected ways.⁸² Jacqueline de Romilly points out that the Greeks often aligned Gorgias' way of twisting words together with "magic."⁸³ Athanasius wrote of Gorgias' rhetoric,

Many have displayed it in figures of thought and tropes, but especially Gorgias, since he was most affected; during the course of the very narrative in his *Funeral Oration*, not venturing to say "vultures" he spoke of "animate tombs" (DK 5a).

Besides offering an example of one of Gorgias' most notorious tropes, Athanasius' matching of "figures of thought" with tropes reveals the connection between tropes, language, and thought that the sophists probably made themselves. For the sophists, tropes were figurative devices with which a speaker could 'turn' listeners' *logoi*, or their rational structures/accounts of reality. Successful tropes, they believed, could change one's perspective, one's way of thinking about things, and even the way one talks. Indeed, the contemporary usage of the phrase "figures of speech" to mean 'metaphor' and other tropes still retains a suggestion that figures of speech shape and give form (figures) to *logos* (speech and thought).

In the modern sophistic tradition, however, the meaning of the term 'metaphor' has in many ways been broadened to become a synonym for 'trope;' so at risk of some confusion, I will use the term 'metaphor' to mean what the sophists probably meant by

⁸² Consigny, "Gorgias Use of the Epideictic" 289; Richard Enos, *Greek Rhetoric Before Aristotle* (Prospect Heights, Ill.: Waveland, 1993) 61.

⁸³ Jaqueline de Romilly, "From Aphorisms to Theoretical Analyses: The Birth of Human Sciences in the Fifth Century B.C.," *Diogenes* 144 (1988): 5-6.

'trope.'⁸⁴ In the essay "Metaphor as Rhetoric," Wayne Booth suggests that this broadened meaning of metaphor is widespread in modern rhetoric. Using the metaphor 'We have here three different breeds of cat' as an example, Booth writes that

"Classical rhetoricians ... would say the sentence contains no metaphors; dead ones are not just dead, they are no longer metaphors.... At the other extreme, some would claim that all my terms were metaphors, and they would seek, though not always find, philological evidence to prove that they were originally "motivated." Or they might, like Paul de Man, seek to show the inescapable metaphorical quality of all human discourse."⁸⁵

As Booth points out, this broadening of the meaning of 'metaphor' has extended the influence of metaphor far past the simple 'X is Y', 'Man is a Wolf'. 'America is a melting pot' format that is often prescribed in textbooks or style manuals.⁸⁶ The change, however, toward this broader meaning over the last century has been gradual rather than sudden. Nietzsche was probably the first to revive a rather sophistic understanding of trope but referred to it as "metaphor." Nietzsche writes,

What therefore is truth? A mobile army of metaphors, metonymies, and anthropomorphisms: in short a sum of human relations which became poetically and rhetorically intensified, metamorphosed, adorned, and after long usage seem to a nation fixed, canonic, and binding; truths are illusions of which one has forgotten that they are illusions; worn out metaphors which have become

⁸⁴ Complaints of this nature can be found in David Cooper, *Metaphor* (Oxford: Basil Blackwell, 1986); and Eva Kittay, *Metaphor: Its Cognitive Force and Linguistic Structure* (Oxford: Clarendon, 1987).

⁸⁵ Wayne Booth, "Metaphor as Rhetoric," *On Metaphor*, ed. S. Sacks (Chicago: Chicago UP, 1979): 49.

⁸⁶ Booth, "Metaphor as Rhetoric" 48.

powerless to affect the senses; coins which have their obverse effaced and now are no longer of account as coins but merely as metal.⁸⁷

The sophists, especially Gorgias, would have probably without reservation agreed to Nietzsche's understanding of metaphor (i.e. as trope) and its relationship to truth. Much like Nietzsche, they would have assumed that the beliefs humans take to be true are merely the end results of 'turns' of thought and language (*logos*). Also like Nietzsche, Gorgias would have stressed that the influence of speech (*logos*) is unnoticed and illusionary, inviting humans to accept their metaphors as certain "reality."⁸⁸ But, as Nietzsche argues, such truths are illusions or worn out metaphors "of which one has forgotten they are illusions."⁸⁹

Unfortunately, though, rhetoricians have only fragments from which to puzzle over what the "older" sophists might have meant by 'trope.' Nietzsche, meanwhile, does not offer a comprehensive view of metaphor, only intriguing directions. So, we must turn to the what many see as the modern sophistic tradition in rhetoric. Indeed, I believe Donald Davidson in his essay "What Metaphors Mean" offers an explanation for metaphor that is closest to what the sophists might have meant by 'trope.' Like the sophists, Davidson points out that features of language, including metaphors, are essentially interpretive and situational in nature. He writes,

Metaphor is the dreamwork of language and, like all dreamwork, its interpretation reflects as much on the interpreter as on the originator ... the act of interpretation is itself a work of the imagination. So too understanding a

⁸⁷ Friedrich Nietzsche, "On Truth and Falsity in the Extramoral Sense," *Essays on Metaphor*, ed. W. Shibles. trans. Mugge, M.A. (Whitewater, Wisc.: Language Press, 1972): 5.

⁸⁸ Consigny, "Sophistic Freedom: Gorgias and the Subversion of Logos" 230.

⁸⁹ Nietzsche, "On Truth and Falsity in the Extramoral Sense" 5.

metaphor is as much a creative endeavor as making a metaphor, and as little guided by rules.⁹⁰

Critiquing the interaction view of metaphor as developed by Richards and Black, Davidson disputes the notion that metaphors create or carry a special cognitive content that makes them “non-literal.” He writes

I agree with the view that metaphors cannot be paraphrased, but I think this is not because metaphors say something too novel for literal expression but because there is nothing there to paraphrase a metaphor doesn't say anything beyond its literal meaning (nor does its maker say anything, in using the metaphor, beyond the literal).⁹¹

Davidson's point is subtle but important. He argues that a metaphor does *not* contain a meaning that is somehow ‘outside’ our normal use of literal language. Rather, “a metaphor makes us attend to some likeness, often a novel or surprising likeness, between two or more things.”⁹² Moreover, Davidson points out that a finite meaning or cognitive content is not contained by the metaphor itself; instead, the ‘meaning’ of the metaphor is brought about by a reader's or listener's *interpretation* of the relationship between two or more contrasting concepts. Reinforcing this point, Davidson writes, “when we hesitate, it is usually to decide which of a number of metaphorical interpretations we shall accept.”⁹³ As such, no special meaning or insight is *transferred* by the metaphor to listeners or readers; rather, each person who experiences a particular metaphor interprets it in his or her own way, according to the rhetorical situation in

⁹⁰ Donald Davidson, “What Metaphors Mean,” *On Metaphor*, ed. S. Sacks (Chicago: Chicago UP, 1979): 29.

⁹¹ Davidson, “What Metaphors Mean” 32.

⁹² Davidson, “What Metaphors Mean” 31.

⁹³ Davidson, “What Metaphors Mean” 33.

which the metaphor is used. Davidson points out, however, that we are always in this type of interpretive relationship with discourse, so it is hard to argue that metaphors are not another form of 'literal' language. Indeed, Davidson's concern is that if we accept that metaphors have a special cognitive content (other than their literal meaning), then we must also assume that metaphors are getting at something 'outside' our language, or that they are transcending our language in some way. He writes, "A consequence is that the sentences in which metaphors occur are true or false in a normal, literal way, for if the words in them don't have special meanings, sentences don't have any special truth."⁹⁴

How should we then understand metaphor? If metaphors are regular features of literal language, then they can be understood to be common, normal features of discourse, including scientific discourse. Indeed, Davidson claims that metaphors are distinguished by their *use* and not by a supposed special cognitive content that is brought about by an interaction between the words themselves. He notes that "Metaphor makes us see one thing as another by making some literal statement that inspires or prompts the insight."⁹⁵ Moreover, Davidson writes, "metaphors... provide a kind of lattice... through which we view relevant phenomena."⁹⁶ In other words, *metaphor invites interpreters to conceive and experience one thing in terms of another by urging perspectives or points of view that govern the way people interpret and discourse about their situations.* For some people, a particular metaphor might seem meaningless or even absurd. For others, it might be interpreted to be a "truth" or "common sense." And for yet another group of people, the same metaphor might be

⁹⁴ Davidson, "What Metaphors Mean" 39.

⁹⁵ Davidson, "What Metaphors Mean" 45.

⁹⁶ Davidson, "What Metaphors Mean" 43.

taken to be profound. Indeed, one often finds that the meaning of a metaphor, like art, is in the eye of the beholder. By bringing two or more concepts into contrast in a novel way, new metaphors often invite listeners or readers to interpret a situation differently than they might have before. More familiar metaphors, on the other hand, often offer enduring perspectives from which a person, even a culture, conceives and discourses about reality.

Once a sentence is taken metaphorically, however, no finite meaning is transferred by the metaphor itself. Rather, it is up to the interpreter to “hunt out” the metaphor’s implications. Thus, new metaphors have an open-ended nature that invites interpretation and reinterpretation. Stressing this point, Davidson writes,

If what the metaphor make us notice were finite in scope and propositional in nature, this would not in itself make trouble; we would simply project the content the metaphor brought to mind onto the metaphor. But in fact there is no limit to what a metaphor calls to our attention, and much of what we are caused to notice is not propositional in nature. When we try to say what a metaphor “means” we soon realize that there is no end to what we want to mention.⁹⁷

Consequently, by reinforcing the interpretive nature of metaphor and claiming literal status for it, I believe Davidson renews the sophistic notion of tropes as ‘turns’ in the *logoi* of the members of an audience. New metaphors, though they grab our attention, do not have a special cognitive content that somehow gets beyond one’s literal language or rational account of reality (*logos*). Rather, their contrastive, open-ended nature urges ‘turns’ in an interpreter’s rational account, encouraging the listener or reader to interpret their situations from a particular perspective. Indeed, Davidson claims that new metaphors create meaning for an interpreter because they seem “patently false” in their

⁹⁷ Davidson, “What Metaphors Mean” 44.

contexts, urging interpreters to hunt out new literal meanings that are more appropriate to the context in which the metaphors are expressed.⁹⁸ Reminiscent of Gorgias' rhetoric, Davidson claims that "absurdity or contradiction in a metaphorical sentence guarantees we won't believe it and invites us, under proper circumstances, to take the sentence metaphorically."⁹⁹

In sum, when one assumes that change is the norm in human understanding, one then can say that metaphors are not exceptions or abnormalities that cause change in an otherwise stable scheme; rather they are a normal feature of discourse that come about because language, thought, and reality are inevitably undergoing change. Whether one adopts an "interaction" view of metaphors or an "interpretive/sophistic" view like the one I believe is offered by Davidson, the scholars that support these views agree that metaphors bring about change in human understanding by altering the way one conceptualizes reality. In other words, as Black and Davidson both note, a metaphor brings about changes in the way humans view their physical and social situations. The critical difference between the interaction and interpretive views of metaphor is the difference between the presumption of conceptual stability held by the former and a presumption of conceptual change held by the latter. In the interaction view, metaphors *cause* changes in an otherwise fixed set of beliefs (i.e. paradigm, schema, model) by creating special meaning, insight, or "ontological flashes" that get 'outside' literal thought and language. The interpretive view of metaphor, on the other hand, suggests that metaphors are natural, contrastive features of a changing reality in which thought and language (*logos*) are inevitably in flux. Therefore, in the interpretive

⁹⁸ Davidson, "What Metaphors Mean" 40.

⁹⁹ Davidson, "What Metaphors Mean" 40.

view, a new or emergent metaphor *urges* people to interpret their situation differently than they might have otherwise.

Metaphor, Invention, and Conceptual Change in Science

Now, let us address directly the main premise offered at the beginning of this chapter—that metaphors in scientific discourse can serve as a basis of invention for scientific arguments. In essence, when a metaphor is interpreted, I believe it invites the interpreter to conceptualize or re-conceptualize features of reality from a particular point of view. Or, as Burke claims, “For *metaphor* we could substitute *perspective*.”¹⁰⁰ Or, as Rorty claims, “A metaphor is ... a call to change one’s language and one’s life, rather than a proposal about how to systematize either.”¹⁰¹ But metaphors offer only a site of departure, a place from which to build an argument. They are not the argument itself. Toulmin also makes this point in a somewhat different way. He writes that scientific discovery is a matter of “coming to think” about phenomena in a “new way.”¹⁰² Nevertheless, this change in perspective, as Toulmin notes, is only the first step in the development of new theories or descriptions of natural phenomena. After one experiences a change in perspective, he points out, it ultimately leads scientists to address the question, “What sort of demonstration will justify us in agreeing that, whereas this was not previously known, it can now be regarded as known?”¹⁰³ If Toulmin is correct, then one can draw clear connections among scientific inquiry, the invention of scientific discourse, and metaphor. After all, changes in perspective, as Burke points out, are for the most part motivated by metaphors. Once a new

¹⁰⁰ Burke, *A Grammar of Motives* 503.

¹⁰¹ Richard Rorty, *Essays on Heidegger and Others* (Cambridge: Cambridge UP, 1991) 12.

¹⁰² Toulmin, *The Philosophy of Science* 17-22.

¹⁰³ Toulmin, *The Philosophy of Science* 17.

perspective is embraced, arguments are then invented that interpret and explore the implications of the new metaphor that urges that perspective.

If so, then what roles do metaphors play in the invention of scientific arguments? As I will show in the following analyses of the seminal texts of the quantum theory, metaphor tends to serve three main roles in the invention of scientific arguments. First, metaphors can become ‘dominant’ or ‘root’ metaphors that, as Burke points out, guide the way whole schools in the scientific community interpret reality. These metaphors more or less shape scientists’ everyday interpretations of reality, even in ways in which they might not be aware. For example, the metaphor ‘nature is a machine’ was a powerful dominant scientific metaphor that emerged during the Renaissance and became the guiding perspective of Enlightenment science. Offering an example of one of this metaphor’s first uses, Kepler wrote in 1605, “I aim to show that the celestial machine is to be likened not to a divine organism but to a clockwork.”¹⁰⁴ During the next century after Kepler many scientists came to assume implicitly that nature is a dispassionate, rigid, and inorganic machine that works according to impartial, predictable laws.¹⁰⁵ Galileo, for example, argued that the motion of the planets followed mechanical laws as dictated by mathematics.¹⁰⁶ William Harvey reinterpreted the heart to be a mechanical pump, “a piece of machinery in which though one wheel gives motion to another, yet all the wheels seem to move simultaneously.”¹⁰⁷ And later, Descartes translated mechanism into a philosophy of nature—

¹⁰⁴ Quoted in Holton, *Thematic Origins of Scientific Thought* 56.

¹⁰⁵ Hugh Kerney, *Science and Change, 1500-1700* (New York: McGraw-Hill, 1971).

¹⁰⁶ Kerney, *Science and Change* 144.

¹⁰⁷ Charles Gillespie, *The Edge of Objectivity* (Princeton: Princeton UP, 1960) 73.

And I have been greatly helped by considering machines. The only difference I can see between machines and natural objects is that the workings of machines are mostly carried out by apparatus large enough to be readily perceptible by the senses... whereas natural processes almost always depend on parts so small that they utterly elude our senses.¹⁰⁸

The dominant metaphor ‘mechanism’ was—and to some extent still is—such a strong influence on the way scientists conceptualized and talked about nature that it was often hard for post-Enlightenment scientists to interpret nature any other way. In fact, it is still common to hear one talk about the “workings of nature,” “the forceful wind,” “an energetic personality,” or “a ball springing off a bat.” Dominant metaphors, like the ‘mechanism’ metaphor, often become so ingrained in the way scientists conceptualize reality and invent their arguments that these metaphors are sometimes held to be certain and immutable. In the end, though, these dominant metaphors, like ‘nature is a machine,’ ‘nature is causal,’ or ‘nature is determinate,’ only offer a temporal sense of stability to the scientific community, urging scientists of particular schools or eras to maintain more or less similar interpretations of nature. Lakoff and Johnson call these sorts of dominant metaphors, “metaphors we live by,” suggesting that some metaphors are “pervasive in every day life, not just in language but in thought and action.”¹⁰⁹

Second, metaphors often play an “emergent” role in the invention of scientific arguments. By emergent, I mean that ‘doing science’ often brings concepts into contrast in ways that create new metaphors. These emergent metaphors then urge scientists to interpret phenomena from a new or different perspective. For example, consider the metaphor ‘light is a wave’ developed by Christiaan Huygens in *Traite de la Lumiere* (1690). He wrote, “[light] spreads ... by spherical surfaces and waves: for I

¹⁰⁸ Quoted in Kerney, *Science and Change* 156.

¹⁰⁹ Lakoff and Johnson, *Metaphors We Live By* 3.

call them waves from their resemblance to those which are seen to be formed in water when a stone is thrown into it." Through the perspective offered by this metaphor, Huygens proceeded to reinterpret the phenomenon of light in terms associated with waves, illustrating how 'light waves' create interference patterns when passing through two slits, much like water waves. Furthermore, he claimed that light, as a wave, must transverse in a medium (i.e. aether) much as waves move in water. The metaphor 'light is a wave,' therefore, became the basis of invention for Huygen's argument. Once he embraced the perspective offered by the metaphor, Huygens began developing demonstrations and other means of argument through which he might explore the implications of the metaphor and demonstrate its usefulness.

Emergent metaphors create an incongruity in the body of scientific beliefs, urging the scientific community to address the implications of these metaphors through argumentation. On one hand, members of the scientific community might reject arguments based on an emergent metaphor as meaningless, absurd, or misguided, thus restoring harmony to their rational accounts of reality by denying the metaphor any status as truth or knowledge. This sort of rejection is common in science, as in other intellectual disciplines. Sometimes, though, despite the seeming falseness or absurd truth of a metaphor, as Davidson calls it, scientists might embrace an argument invented through an emergent metaphor because it fills a gap, solves a problem, allows them to make do in a way that their previous beliefs could not. Other scientists, then, might apply the metaphor to other related phenomena, reinterpreting things once known from a new perspective.

Of course, most emergent scientific metaphors do not guide the invention of major theoretical works or form the basis of whole schools of thought. Usually they offer small 'turns,' or changes, to the rational accounts of members of the scientific community, leading to the development of typical scientific contributions. Indeed, a

vast majority of scientific discourse is designed to make these sorts of small changes to the beliefs of others. Physicists David Bohm and David Peat argue this point in *Science, Order, and Creativity*. They suggest that “metaphorical play” is *necessary* to creativity in science. Indeed, the mere activity of doing science, Bohm and Peat claim, inevitably brings metaphors forward. They write,

Within this play it is not to be taken for granted that new things must always be different or that they can never in any significant way be related to what came before. Indeed, it might be suggested that the more different things are, the greater may be the importance in seeing how they are similar, and likewise, the more similar things are, the greater may be the value in perceiving their differences.¹¹⁰

Bohm and Peat criticize the Kuhnian notion that revolutions occur in any sort of either/or procedure in which incommensurable paradigms (or metaphors) struggle for complete dominance. Rather, they stress that the *pluralism* created by the give and take among different scientific beliefs and theories that urges concepts to play with one another in ways that gradually change scientists’ perspectives and lead to new theories. They argue that metaphors come about naturally because the activities of science create a “metaphorical play,” that inevitably spins off new metaphors and thus leads the way for the development of new descriptions of reality.¹¹¹

Third, if they are successful, the final role scientific metaphors serve in invention is to become “dead” metaphors that make up the accepted features of scientific discourse and thus scientists’ lexicon. Eventually, metaphors turn into standard, relatively unnoticed, features of scientific discourse that provide the constituent

¹¹⁰ David Bohm and David Peat, *Science, Order, and Creativity* (New York: Bantam, 1987) 49.

¹¹¹ Bohm and Peat, *Science, Order, and Creativity* 49.

concepts used to develop scientific arguments. Some more prominent examples of scientific dead metaphors might include atoms, cells, electrons, time, space, gravity, photons, aether, and so on. At some point, all these concepts were newly emergent metaphors; but as they gained acceptance and usage by the scientific community they lost their supposed “figurative” status. In other words, as Davidson notes, metaphors die when their novelty fades away and they become a regular part of how one interprets and talks about reality.¹¹² Is the heart really a pump? Are humans actually primates? Is the earth orbiting the sun? Is light a form of radiation? These dead metaphors are the basis of scientists’ and our accounts of reality. In fact, it is hard to conceptualize the heart, humans, earth, or light in ways that avoid these metaphors. We rely on these dead metaphors and they’ve proven their usefulness toward explaining our physical and social contexts. So, they are held to be literal and true with only periodic challenges. Interestingly, though, it is also important to recognize that all the concepts mentioned in this paragraph have undergone changes in meaning for decades, even centuries. Though some have experienced rapid change in meaning and others slow change, all these dead metaphors have been reinterpreted over time to suit the needs of the people and communities who used them.

The analyses of the scientific texts of Planck, Einstein, and Bohr in the following three chapters, therefore, will be based on the premise that metaphors are the creative impetus that urge both scientific inquiry and the invention of scientific discourse into motion. When interpreted, scientific metaphors often lead to new perspectives and thus ‘turn’ the rational accounts, or *logos*, of members of the scientific community, inviting them to invent arguments that offer new explanations for phenomena. Interpreting and employing a new metaphor, however, is not an isolated

¹¹² Davidson, “What Metaphors Mean” 43.

event. It invariably urges a broader turn in beliefs by creating new ways from which to make sense of reality. Moreover, as Burke points out, some metaphors potentially lead to whole movements in science in which whole sets of beliefs are reinvented to cohere with the perspective offered by a new metaphor.¹¹³

Conclusions

In this chapter, I have developed an understanding of scientific metaphor that stresses the interpretive nature of metaphors in scientific discourse. I believe the relationship between metaphor and invention is crucial to understanding how metaphors are used in scientific discourse. In passing, other scholars have also noted this relationship between metaphor and the invention of scientific arguments, but few have explored the implications of such a close connection between metaphor and the development of scientific theories and descriptions. In the following three chapters, I will shift from this chapter's rather theoretical discussion of scientific metaphor to analyses of actual metaphors in the texts of Planck, Einstein, and Bohr. I will show that the metaphors that emerge in these texts invited these scientists to adopt a quite novel perspectives toward reality and then invent arguments that explored the implications of each new metaphor.

¹¹³ Burke, *Permanence and Change* 95.

CHAPTER THREE

THE EMERGENCE OF A DOMINANT METAPHOR IN PHYSICS: MAX PLANCK'S 'QUANTUM' METAPHOR

A New Scientific Truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it.

Max Planck

To this point I have discussed the theoretical basis for an “interpretive” view of metaphor that is in line with the modern sophistic tradition in rhetorical theory. I have argued that metaphor, understood broadly as a device for interpreting one’s physical and social situation from a particular perspective, plays a basic role in the invention of scientific arguments. Indeed, this relationship between metaphor and invention in scientific discourse is *the* significant issue that serves as the focal point for the remainder of this study.

But how does the previous two chapters’ rather abstract discussion of metaphor and invention lend itself to the analysis of actual scientific texts? To address this practical question, in this chapter I will first develop a bridge between theory and analysis by explaining how the interpretive view of metaphor, discussed in the previous chapter, can be used to interpret scientific texts. Specifically, my aim is to illustrate a methodology that allows us to look at scientific texts as historical artifacts that offer insight into the invention of scientific theories. Then, in the remainder of this chapter, I will use this methodology to analyze Planck’s original 1900 paper in which he first developed the “quantum metaphor” that serves as a basis for the invention of arguments in the quantum theory.

Metaphorical Analysis

To start us out, let me first point out that rhetoricians of science often approach scientific articles differently than historians, philosophers, and sociologists. Typically, when historians, philosophers, and sociologists research the genesis of a particular theory or movement in science, they more or less consider the important texts of that movement to be final products that sum up the scientists' efforts. In effect, the texts are treated as conclusive statements of fact and not as mechanisms through which the scientists invented their ideas. Consequently, these scholars focus on reconstructing the historical narrative that led up to the final development of a scientific achievement expressed in the final text. Rarely, however, do historians, philosophers, and sociologists address the written composition of the scientific text in an analytical or critical way. Rather, these scholars are typically concerned with the so-called content or ideas that the final scientific text expressed. Rhetoricians of science, on the other hand, view scientific texts as artifacts unto themselves that can illuminate the process that went into the development of particular theories. Therefore, a close analysis of the final text, it is assumed, can lead to an understanding of how the scientific text and the beliefs it expressed were invented.¹ In other words, rhetoricians approach scientific texts with the assumption that the *rhetoric* of a particular text can offer a means through which the genesis and continuation of a particular movement in science can be further understood.

For these reasons, rhetoricians of science often find that close analyses of scientific articles can yield valuable information toward reconstructing how a particular theory was invented. For example, Miller in her analysis of the work of Watson and Crick's original papers on the DNA double-helix structure shows how the rhetorical

¹ Gross, *The Rhetoric of Science* 12-16.

concept of *kairos* illuminates the reasoning behind the rhetorical choices that went into developing Watson and Crick's theory and arguments.² Likewise, Gross's rhetorical analysis of Newton's *Opticks* shows how Newton adjusted his rhetorical strategies in order to develop a theory of light that allowed "fellow physicists to believe that an adherence to the new did not entail a fundamental rejection of the old."³ Indeed, these sorts of studies apply various rhetorical analysis methodologies to seminal scientific texts to illustrate not only the persuasion strategies that went into the presentation of important theories but also the invention strategies that were evident in the development of the arguments in which these theories were expressed. Of course, other historical and philosophical factors are an important part of these analyses, but the texts themselves form a critical focal point for rhetorical analyses.

In the following rhetorical analyses of Planck, Einstein, and Bohr's original quantum theory texts, I will use metaphorical analysis to illuminate how these particular texts and the ideas they contain were invented through the interpretation of metaphors. Given the assumption that the interpretation of metaphors leads to the invention of scientific arguments, it stands to reason that an analysis of the metaphors within these scientific texts would illustrate, in part, how these scientists came to view and discourse about natural phenomena differently than they might have before. Also, by drawing out the "dominant" or "root" metaphors that underlie scientific movements, including the quantum theory, one can illustrate how movements in science rise, endure, and eventually fall. In a sense, one can trace what Burke calls "fertile metaphors" through the documents of science, observing how particular metaphors become relevant and useful to the society in which they are used. In the end, I believe such analyses do more

² Miller, "*Kairos* in the Rhetoric of Science" 310-327.

³ Gross, "On the Shoulders of Giants: Seventeenth-Century Optics as an Argumentation Field" 1-17.

than tell us about scientific discourse: they illustrate through texts how scientists invent their arguments and how these arguments then change the beliefs of the scientific community.

To analyze metaphors in scientific texts from an interpretive view, one can follow four basic steps. First, the analysis must be thoroughly contextualized through a description of the rhetorical situation in which the metaphor was introduced or used. Because the interpretation of new metaphors leads to changes in perspective, it is important that the theories and beliefs of the scientific community prior to the emergence of a new metaphor be understood and explained. Only then can one distinguish and illuminate the change brought about through the introduction of a new metaphor to the scientific community. An analysis can be “contextualized” through the reconstruction of the historical narrative in which the metaphor was used. This can be accomplished through a review of relevant historical events, correspondences among scientists, memoirs, and secondary historical or philosophical sources that discuss the text being analyzed.

Second, through a close reading of the text being analyzed, the dominant and emergent metaphors are identified. As Lakoff and Johnson point out, metaphors only periodically take on the typical ‘X is Y’ or ‘America is a melting pot’ format; instead, metaphorical concepts typically form consistent patterns or perspectives that encompass whole sets of words. For example, Lakoff and Johnson point out that the metaphor ‘time is money’ is exhibited in various forms like “How do you spend your time?” “That flat tire cost me an hour,” or “You’re running out of time.”⁴ In essence, the ‘time is money’ metaphor is a basic metaphor that characterizes a whole system of metaphoric phrases that create a coherent perspective. In scientific texts, one can find similar

⁴ Lakoff and Johnson, *Metaphors We Live By* 8.

entailments from a simple metaphor. For example, the phrase 'nature is a machine' is a simple metaphor that is exhibited in various forms through Kepler's 'the celestial machine is a clockwork' or Harvey's 'the heart is a pump,' or Descartes' 'God is a Divine Engineer.' Indeed, the basic metaphor 'nature is a machine' is essentially a simple expression for an entire coherent system of metaphorical concepts. As such, one can identify and gather together these metaphorical concepts through a close reading of one or more texts and use them to identify a particular perspective brought about through the interpretation of an emergent or dominant metaphor.

Third, once the emergent or dominant metaphors have been identified, one then analyzes the collective perceptives that the metaphors and their system of metaphorical concepts bring about. The purpose of this analysis is to show how an emergent or dominant metaphor served as a basis of invention for the argument expressed in the analyzed text. Because my three analyses of Planck, Einstein, and Bohr's papers below illuminate the changes in perspective brought about by the interpretation of scientific metaphors, I will be particularly interested in showing how the perspectives offered by new metaphors, especially the quantum metaphor, contrasted with the prior beliefs of the scientific community. I will bring the emergent metaphors in these texts into contrast with the previously developed historical narrative to illustrate how the new perspectives expressed by Planck, Einstein, and Bohr violated the scientific orthodoxy of their day. Then, I will show how these metaphors and the perspectives they created served as a starting place for the invention of the text being analyzed.

Finally, the significance of the emergent or dominant metaphors is discussed within the broader historical narrative in which the analyzed text is situated. Given the fact that metaphors invite other scientists to change their perspectives and beliefs about nature, one can show how particular metaphorical concepts fit or formed the basis of entire scientific movements. In essence, this final step elaborates on the future of

particular metaphors through a discussion of their future interpretation by other scientists. With this fourth step completed, an analysis attempts to show how particular metaphors invited scientists to argue for stability or change in the theories and beliefs of the scientific community.

Overall, the purpose of a metaphorical analysis, like any rhetorical analysis, is to illuminate the rhetoric of a particular text. The three texts analyzed in this study will be discussed separately with the idea that each analysis can stand alone; however, together I believe these analyses allow one to trace particular quantum theory metaphors as they emerge in the scientific community over time. Consequently, a comprehensive study of these metaphors at three different time periods in the development of the quantum theory provides a good illustration of how new beliefs emerge, gain influence, and eventually dominate the beliefs of the scientific community.

Max Planck and the Quantum Mystery

Let us first analyze Planck's 1900 paper in which the possibility of a quantum interpretation of nature was first indicated. Planck's initial genesis of the quantum theory, like the development of many theories in science, presents us with a mystery. Traditionally, Max Planck has been given credit for introducing the 'quantum postulate' in a December 14, 1900 speech to the German Physical Society. Yet, in the mythology of science, it has often been suggested that Planck took the first step of the quantum theory quite by accident, and that he did not realize the radical nature of his claims until years later.⁵

Planck's quantum postulate is the centerpiece of much of quantum physics. It suggests that energy must be divided into *discontinuous* or *discrete* bundles called

⁵ This assertion can be found in numerous histories of quantum theory. Kuhn, however, offers the most thorough discussion of the issue in Thomas Kuhn, *Black-Body Theory and The Quantum Discontinuity* (New York: Oxford UP, 1978).

'energy quanta.'⁶ In a more generalized form, the "quantum hypothesis" prescribes that physicists must interpret natural phenomena in discontinuous terms; however, the quantum hypothesis also suggests that the discreteness of nature is so nearly infinitesimal that human senses typically perceive natural phenomena to be continuous. For example, to people walking on a beach, the sand all around them appears to be something continuous; however, if they looked more closely, they would see that the body of sand at their feet consists of discrete grains, making the sand discontinuous. In a sense, one might say that these grains of sand are the "quanta" of the beach. Of course, this analogy is rather elementary, but its simple quality hints at the fundamental nature of the quantum hypothesis. When the quantum hypothesis is used to interpret phenomena like energy or light, which appear to be continuous, descriptions of a quantum reality start to become rather complex.

The mystery concerning the development of the quantum theory is whether Planck realized the importance of this discontinuity when he 'discovered' the quantum postulate. Seeking to dispel the doubts about Planck's work, Nobel physicist Max Born, a friend and colleague of Planck, emphatically defended Planck's initial development of the quantum theory. He wrote,

Planck was perfectly clear about the importance of his discovery.... His modest and reluctant way of speaking about his work has caused the impression that he did himself not quite believe in his result. Therefore, the opinion spread, especially outside Germany, that Planck "did not seem to know what he had done when he did it," that he did not realize the range of his discovery.⁷

⁶ Polkinghorne, *The Quantum World* 6. The most accessible account of the quantum theory is in Pagel's *The Cosmic Code*.

⁷ Max Born, "Max Karl Ernst Ludwig Planck," *The World of the Atom*, ed. H. Boorse, and L. Motz (New York: Basic Books, 1966): 473.

More recently, though, in a meticulous work on the origin of the quantum theory, Thomas Kuhn claims that Planck did *not* recognize the importance of his ‘discovery.’ Kuhn argues that “Planck himself did not publicly acknowledge the need for discontinuity until 1909, and there is no evidence that he had recognized it until the year before.”⁸

So, we have a mystery. Who originated the quantum hypothesis? Any reader of the history of science soon finds that it is abundant with these sorts of who-done-it mysteries. Did Galileo or Newton discover inertia? Did Newton or Leibniz discover the calculus? Did Lorentz, Poincare, or Einstein discover the relativity? Though we often settle on one scientist for the accolades, it is often hard to pin down where a particular movement in physics started. Indeed, one thing we *do* observe in the history of science is that new beliefs and new theories rarely arrive in clear, undeniable arguments. Rather, new beliefs seem to emerge hesitantly in the papers of different scientists. Only later, when scientists are honored for their work, do historians and other scientists start sparring over who ‘found’ what and where. As mentioned in the last chapter, though, the problem with these debates is that they assume that there is one and only one thing to be ‘discovered.’ Yet, when one looks critically at the historical texts of science and the arguments in which so-called ‘discoveries’ were expressed, it soon becomes apparent that the invention of scientific theories and beliefs is a richly complex endeavor that includes a great amount of creativity, trial and error, interpretation, and social interplay. In the midst of this tangle, there is rarely evidence of a flash of insight in which one physicist steps forward, never to look back. Historian Gerald Holton points out that this complexity is especially true of the seminal works in science. He writes,

⁸ Kuhn, *Black-Body Theory and The Quantum Discontinuity* 140.

There we are more likely to see plainly the illogical, nonlinear, and therefore “irrational” elements that are juxtaposed to the logical nature of the concepts themselves. . . . None of these elements fit in with the conventional model of the scientist; . . . and yet they play a part in scientific work.⁹

In the remainder of this chapter, I will use metaphorical analysis to illuminate the quantum hypothesis as a metaphor that emerges innocuously in Planck’s December 14, 1900 paper, “On the Theory of the Energy Distribution Law of the Normal Spectrum.”¹⁰ Interestingly, I will show that the quantum postulate is for the most part a parenthetical feature of Planck’s argument for an energy distribution law. Indeed, I will argue that he invented his overall argument in this paper through a perspective offered by a quite different metaphor, ‘energy spectrum is an entropic phenomenon.’ The quantum postulate is certainly not the focus of his paper, no less a call for a fundamental theoretical change in physics. And yet, as I will show, the subtle emergence of the quantum postulate as a new metaphor in Planck’s work illustrates how new ways of interpreting reality in science often come about through metaphors that spin out of the normal activity of ‘doing science.’ I will show that new metaphors emerge naturally as a result of scientific inquiry, because the mere act of doing science puts beliefs into contrast, urging scientists to adopt new perspectives toward interpreting phenomena in nature.

Rhetorical Situation

Before analyzing Planck’s paper, let us first look at the rhetorical situation in which Planck and his argument were immersed. If we were to cast Planck’s development of the quantum postulate into the popular revolution myth of the history of

⁹ Holton, *Thematic Origins of Science* 8.

¹⁰ Reprinted and translated in D. ter Haar, *The Old Quantum Theory* (New York: Pergamon, 1967) 82-90.

science, we would need to refer to it as an almost unnoticed shot in the dark. Little attention was paid to Planck's December 14, 1900 paper in which he first suggested that energy could be considered discontinuous or "quantized." It was only five years later that scientists—most notably an unknown patent clerk, Albert Einstein—began to take notice. Even Planck himself reports that he was troubled by the discontinuous quality of his new postulate and that he struggled for years to reform his 'quantum of action' into classical physics. He writes in his *Scientific Autobiography*:

My futile attempts to fit the elementary quantum of action somehow into the classical theory continued for a number of years, and they cost me a great deal of effort. Many of my colleagues saw in this something bordering on a tragedy. But I feel differently about it. For the thorough enlightenment I thus received was all the more valuable.¹¹

Planck's quantum postulate was indeed an assertion that called on scientists to interpret phenomena in nature very differently. Previous to the quantum hypothesis, physicists conceptualized reality in more or less 'continuous' terms, assuming that nature and the universe are ultimately a continuum. Even the limited number of nineteenth century physicists who believed in atomistic theories of nature assumed that a medium, an "aether," permeated 'empty' space, joining all of the universe into a seamless, continuous Being.¹² Atomism, however, was a concept under heavy fire in the second half of the nineteenth century. Highly influential empirical positivists like Ernst Mach, Wilhelm Ostwald, and Pierre Duhem argued very persuasively that atoms were merely metaphysical illusions that did not exist because they could never be observed.¹³

¹¹ Max Planck, *Scientific Autobiography* (New York: Philosophical Library, 1949) 45.

¹² Gillispie, *The Edge of Objectivity* 355.

¹³ Gillespie, *The Edge of Objectivity* 500-503.

Therefore, even the mild quality of discreteness in nature represented in atomic theories of nature was considered skeptically by a majority of the physics community.

To nineteenth century physicists, then, the continuity of nature was mostly unquestionable, and it seemed to manifest itself directly in the mechanical 'laws' of classical physics. For example, Newton's laws, or formulas, of motion were constructed from his differential and integral calculus in which functions are represented by infinitesimally small increments (i.e. continuous).¹⁴ Therefore, motion of any kind, including related concepts like energy, were assumed to be inherently continuous because the calculus, which had proven remarkably useful, dictated that they must be so. Seeming to only reaffirm nature as a continuum, Maxwell's equations and his theories of electromagnetic radiation (light) were based on wave functions, implying that light is made up of continuous waves, not particles. Indeed, Maxwell's equations were so persuasive that late in the nineteenth century, many physicists believed that the field of physics was closing in on a unified theory for physics that would be developed along purely continuous concepts. Stressing this continuity of nature, Mach, Ostwald, and Duhem's arguments against atomism were probably in part emboldened by the increasing evidence, offered by Newton's and Maxwell's theories, that implied nature is continuous.

So, the lack of attention paid to Planck's quantum postulate is for the most part understandable when one considers the rhetorical situation into which it was introduced. In the late nineteenth century, *completion* of the physics enterprise was on the minds of scientists, not large-scale change. Encouraged by Maxwell's coupling of the theories of electricity and magnetism in the 1860s, many physicists were inclined to

¹⁴ N.M Bligh, *The Evolution and Development of the Quantum Theory* (London: Edward Arnold, 1926) 12. Also see Armin Hermann, *The Genesis of Quantum Theory* (Cambridge: MIT P, 1971) 1-3.

believe that the three remaining divisions of physics (i.e. electromagnetism, thermodynamics, and mechanics) would soon come together into one unified theory of the continuum.¹⁵ So, rogue arguments were often dismissed out of hand if they did not obviously fit prevailing theories. In fact—and I believe this was true of Planck’s quantum postulate—a great majority of scientific readers were not prepared to entertain beliefs that violated the so-called ‘absolute’ theories of classical physics. They were more likely to assume that even obvious violations of theories would soon be renovated to fit classical theories. An example of the confidence of nineteenth century physicists is offered in the following 1903 quote by Albert Michelson:

The more important fundamental laws and facts of physical science have all been discovered, and these are now so firmly established that the possibility of their ever being supplanted in consequence of new discoveries is exceedingly remote.¹⁶

Similarly, Lord Kelvin was known to publicly express the opinion that physics was more or less a completed field of study in which only more accurate measurements of known phenomena were needed.¹⁷ Moreover, one of Planck’s professors in 1875 urged him not to study physics, because it was assumed that the recent ‘discovery’ of thermodynamics had for the most part completed the framework of theoretical physics.¹⁸

¹⁵ Maxwell’s theories of electromagnetism explained successfully how light behaves like a wave. Light occurs in the “visible” part of the electromagnetic spectrum.

¹⁶ Albert Michelson, *Light Waves and Their Uses* (Chicago: U of Chicago P, 1903) 23-24.

¹⁷ Steven Weinberg, *Dreams of a Final Theory* (New York: Vintage, 1992) 13.

¹⁸ J.L. Heilbron, *The Dilemmas of an Upright Man: Max Planck as Spokesman for German Science* (Berkeley: U of California P, 1986) 10.

Physics, however, was not dead, just overwhelmingly empirically oriented. Like Kelvin and Michelson, a great number of physicists believed that the real effort of the discipline should be concentrated on developing experimentally exact and certain measurements of all phenomena. However, as physicists developed experimental methods to sharpen the accuracy of their measurements, they began to experience and identify new phenomena that could not be immediately accounted for by classical physics. For example, in the late 1890s alone, experimental physicists identified X-rays (1895), radioactivity (1896), the electron (1897), and radium (1898). Also, an outsider in the physics community, Ludwig Boltzmann, began using statistical means to more productively calculate the thermodynamic properties of fluids and gases. Seeming to contradict the ideal of certainty in physics, Boltzmann's statistical methods for calculating thermodynamic phenomena proved strangely more accurate than conventional mathematics. Boltzmann's outsider status, however, was created by his arguments for an atomistic theory of thermodynamics. Mach and Ostwald were his most ardent critics, persuading many physicists in the late nineteenth century to discount Boltzmann's theories and his methods.

The tacit assumption of a natural continuum and the dominance of empiricism were both powerful influences in the existence of the three prevailing theoretical divisions of the discipline—electromagnetism, thermodynamics, and mechanics. Heavily reliant on continuous 'wave' interpretations of light-related phenomena, electromagnetism was the study of electricity, magnetism, and light. Thermodynamics was the study of heat and energy with a heavy emphasis on fluid gases and liquids. And finally, mechanics (or dynamics) was the study of matter in motion. Indeed, the names of two of these divisions alone signaled the most significant scientific triumphs of the nineteenth century: electro-magnetism combined the fields of electricity and magnetism, and thermo-dynamics combined the fields of heat and motion into a theory

of mechanical energy. Given the trend in which major divisions of physics were being combined, it was thus assumed that eventually the remaining three divisions would be finally collapsed into one universal theory of physics. Then, Planck developed the quantum postulate.

Max Planck and Black Body Radiation

By the late 1890s, Planck was a theoretical physicist in Berlin with a good reputation. For nearly twenty years, he had published prolifically in the area of thermodynamics and by 1897 was known to be one of the major authorities on classical thermodynamics.¹⁹ His specialty was theoretical research on 'entropy' (the second law of thermodynamics) and he was a developer and advocate of theories of thermodynamics that rejected atomism and supported assumptions of an absolute continuum in gases and liquids. This position put him into direct conflict with Boltzmann's atomistic theories of thermodynamics. Throughout the latter half of the 1890s, Planck and his assistant, Ernst Zermelo, debated with Boltzmann publicly about whether physicists should accept an 'absolute' or 'probabilistic' interpretation of entropy in thermodynamics. Put plainly (and far too simply), entropy is the amount of 'disorder' in a system. In the debate with Boltzmann, Planck championed the traditional interpretation of the second law of thermodynamics, which states that the entropy of a system *always* increases (i.e. moves toward disorder). Boltzmann argued that entropy of a system *almost always* increases, forcing one to talk about entropy in probabilistic terms. Eventually, but only late in 1900, Planck conceded to Boltzmann's atomism and interpretation of entropy.

Planck's debates with Boltzmann are important because the topics covered in their arguments carried over into a completely new project that Planck began in 1897.

¹⁹ Heilbron, *The Dilemmas of an Upright Man* 13.

Almost as a diversion from his research on the second law of thermodynamics, Planck began working on the perplexing problem of ‘black body radiation’ that had been a pet project of Gustav Kirchhoff, the retiring professor who Planck was hired to replace at the University of Berlin. In his autobiography, Planck reports that he was initially attracted to the black body radiation problem because he believed it might lead to “something absolute. . . and since I had always regarded the search for the absolute as the loftiest goal of scientific activity, I eagerly set to work.”²⁰ Black body radiation is created by heating a partially evacuated cavity (usually a cube) that is bounded by perfectly reflecting walls. Inside the heated cavity, electromagnetic radiation (light) proceeds to reflect to and fro off the walls. At any constant temperature, the system comes to equilibrium and the radiation develops an *energy spectrum* that includes electromagnetic radiation from the radio to the visible to the ultraviolet ends of the electromagnetic spectrum. At high enough temperatures, X-rays are emitted.

This experiment may sound strange, but it replicates a rather common experience.²¹ If we were to heat a piece of metal, say a rod of iron, to 100 degrees Celsius, the electromagnetic radiation emitted would be in the infrared region. We would then feel heat created by the radiation hitting our skin, but we would not see the radiation because the wavelength would be too large and thus outside the humanly visible part of the electromagnetic spectrum. If we then continued to heat the iron rod to hotter and hotter temperatures, it would eventually emit radiation from higher frequency parts of the electromagnetic spectrum. First, the iron would glow red, signaling that it was emitting low level visible radiation—in addition to infrared. At hotter temperatures, it would emit white light, because white light is a combination of all parts of the visible

²⁰ Planck, *Scientific Autobiography* 34-35.

²¹ Gamow, *Thirty Years That Shook Physics* 9-10. The thought experiment discussed here is an adaptation of Gamow’s example.

spectrum. And at extremely high temperatures, it would begin emitting ultraviolet radiation in addition to all the lower frequencies in the spectrum from radio to infrared to visible radiation. With each rise in heat, the frequency of the radiation and its energy (E) would also rise, accounting for the damage that ultraviolet radiation can cause to the skin.

Capturing Planck's attention, Kirchoff had shown that the 'energy spectrum' created by heating a black body was completely independent of the type of material heated. In other words, whether one is heating iron, coal, or any other black body material, the energy spectrum of the emitted radiation would be the same series of infrared, red, white light, and ultraviolet colors. Kirchoff's conclusion was important because it showed that the energy spectrum does not rely on the type of heated material being used to create the electromagnetic radiation; therefore, he concluded, the energy spectrum is an independent (i.e. "absolute" in classical physics) phenomenon of nature. Kirchoff named this independent phenomena the "normal spectral energy distribution" (called "energy spectrum" from now on). As stated earlier, the complete dependence of the energy spectrum on temperature, not the material, attracted Planck to this curious black body phenomena, because he believed it might lead him to discover something absolute.²²

In most ways, however, the black body radiation problem was not in Planck's normal area of research. Though it dealt with heat and energy—central concerns of thermodynamics—most physicists of his day believed that black body radiation would be explained as an electromagnetic phenomenon, because light played such a prominent role in the energy spectrum. Planck reports that when he began his research on the problem all the physicists at the time were exclusively attempting to explain black body

²² Planck, *Scientific Autobiography* 34-35.

radiation through Maxwell's equations of light.²³ Though at first he also attempted to use Maxwell's equations, he soon realized that "an essential link was missing, without which the attack on the core of the entire problem could not be undertaken successfully."²⁴ After several failures of his own, he reports, "I had no other alternative than to tackle the problem once again—this time from the opposite side, namely, from thermodynamics, my own home territory where I felt myself to be on safer ground."²⁵ The new direction seemed to show almost immediate results; and, in the spring of 1900 Planck reported to the German Physical Society that he had used concepts from thermodynamics to develop a theory of black body radiation that proved the validity of "Wien's law," a previously derived formula for the energy spectrum.²⁶ However, as Planck was proofing the final text for the article, data from new experiments on black body radiation emerged that seemed to contradict his theory. It was soon evident to Planck that his theory and Wien's formula for the energy spectrum were seriously flawed.

The experiments on black body radiation that called into doubt Wien's formula and Planck's theory were conducted by two highly respected experimenters, Heinrich Rubens and Ferdinand Kurlbaum.²⁷ Against all expectations, they showed that the black body 'intensity distribution' of the energy spectrum was shaped like a bell curve rather than as a continuously rising line. In other words, Rubens and Kurlbaum showed that higher frequencies of radiation (ultraviolet or above) are *not* accompanied

²³ Planck, *Scientific Autobiography* 38.

²⁴ Planck, *Scientific Autobiography* 37.

²⁵ Planck, *Scientific Autobiography* 37.

²⁶ Pais, *Niels Bohr's Times* 83-84.

²⁷ Friedrich Hund, *The History of Quantum Theory* (London: Harrap, 1974) 25.

by an ever-increasing level of energy. Rather, at higher and higher frequencies, the energy level of radiation levels off and then goes toward zero.²⁸ This result, by the way, reflects experience because it explains the limited existence and energy of ultraviolet rays and X-rays. In fact, if Wein's formula, based on classical concepts, was correct, materials at any heat would emit dangerous energy levels of ultraviolet radiation and X-rays. Therefore, according to classical physics, looking at our heated iron rod at any temperature except absolute zero should immediately burn our eyes and skin with high energy ultraviolet radiation and X-rays.²⁹ Of course, this does not happen.

Planck went back to work with the new data, and in October 1900 through mainly trial and error, he developed a formula that fit Rubens and Kurlbaum's new experimental data. In a paper to the German Physical Society on October 19, he proposed that the radiation followed the formula

$$j(\nu, T) = A\nu^3 / \exp(B\nu/T) - 1$$

ν is frequency
 T is temperature
 A and B are unknown constants

Confirmation of Planck's new formula was almost immediate. He wrote in his autobiography, "The very next day, I received a visit from my colleague Rubens. He came to tell me that after the conclusion of the meeting he had that very night checked my formula against the results of his measurements, and found a satisfactory concordance at each point."³⁰

²⁸ Gamow, *Thirty Years that Shook Physics* 10-11.

²⁹ Gamow, *Thirty Years That Shook Physics* 17.

³⁰ Planck, *Scientific Autobiography* 40-41.

Nevertheless, even Planck believed that his formula was the result of “lucky intuition” and was not complete until he could explain why it worked.³¹ He set about attempting to derive the formula from other theoretically “proven” proofs. But every attempt to explain the formula through his own beliefs about thermodynamics failed. So, in an “act of desperation,” he completely reconsidered his beliefs about thermodynamics and began to reconceive the black body problem in terms of Boltzmann’s interpretations of entropy and probability.³² This noteworthy change in Planck’s beliefs toward atomism and probabilistic interpretations of entropy was an outright abandonment of his previous theories. And yet, Planck reports that after a few weeks of applying Boltzmann’s methods to the black body problem, “clearness began to dawn on me,” and he had the theoretical description he was seeking.³³

Planck’s 1900 Quantum Paper

Planck’s December 14, 1900 paper, “On the Theory of the Energy Distribution Law of the Normal Spectrum,” which I will now analyze, is often considered the origin of the quantum theory even though Planck did not coin the terms ‘energy quanta’ or ‘quantum of action’ in this article. The article breaks with classical mechanics because it introduces a constant “h” that necessitates energy to be considered ‘discontinuous’ rather than continuous. One of the arguments Planck makes in this paper—one that is familiar to any physics undergraduate—is that energy (ϵ) is equal to the product of a constant (h) and the frequency (ν) of the radiation, or $\epsilon = h\nu$. The h in this relation is called “Planck’s constant.” The relation, $\epsilon = h\nu$, is often called the “quantum postulate.” Interestingly, though, when the position and stress on particular metaphors

³¹ Planck, *Scientific Autobiography* 41.

³² Max Planck letter to Robert Williams Wood, October 7, 1931. Reprinted in Armin Hermann, *The Genesis of the Quantum Theory*, trans. C. Nash (Cambridge: MIT P, 1971) 23.

³³ Max Planck, *The Origin and Development of the Quantum Theory* (Oxford: Clarendon, 1922) 9.

in Planck's 1900 quantum paper are studied, it becomes apparent that he did not see the quantum postulate as the focus of the paper, nor does he even hint that his idea of an 'energy quanta' is a call for major change in the field of physics. Instead, as I will show, Planck's notion that 'energy is discontinuous' is primarily a parenthetical development that spins out of Planck's metaphorical use of concepts from Boltzmann's thermodynamics to invent a theory of black body radiation and the energy spectrum. Toward this end, I will first summarize Planck's paper, identifying and marking the placement of metaphors. Then, I will analyze particular 'clusters' of metaphorical relationships in more depth to show how Planck creates and employs metaphors in his paper.

Overall, Planck's 1900 quantum paper, like most papers to the German Physical Society, is rather short. He begins by reminding the audience of the conclusions of his October 1900 paper in which he introduced the original version of his distribution formula for the energy spectrum. He states,

in my opinion, the usefulness of this equation was not based only on the apparently close agreement of the few numbers, which I could then communicate, with the available data, but mainly on the fact that it gave a very simple logarithmic expression for the dependence of entropy of an irradiated monochromatic vibrating resonator on its vibrational energy. This formula seemed to promise in any case the possibility of a general interpretation.³⁴

For Planck's audience, 'entropy'—itself a newer but mostly dead metaphor (i.e. 'closed systems are entropic') from thermodynamics³⁵—probably did not have an

³⁴ Max Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum," *The Old Quantum Theory*, ed. D. ter Haar (New York: Pergamon, 1967): 82.

³⁵ Clausius in 1854 coined the term "entropy" as a metaphor. He wrote "I propose, accordingly to call S the entropy of a body, after the Greek word 'transformation.' I have designedly coined the word entropy to be similar to 'energy,' for these two quantities are so analagous in their physical

obvious relationship to electromagnetic radiation. So, by suggesting that he would interpret the behavior of the ‘energy spectrum,’ an electromagnetic phenomenon, through the meanings associated with ‘entropy,’ a concept from thermodynamics, Planck created a new metaphor for the audience by bringing these two concepts into contrast. Entropy, as Planck proceeds to define it plainly for his audience, “means disorder.” However, Planck then argues, if one is to apply the concept of entropy to the energy spectrum, one needs to assume that the energy that makes up the energy spectrum is in an equilibrium state of maximum entropy.³⁶ Also, Planck points out—this is a crucial point—in order for his October 1900 formula to work, one must also assume, as Boltzmann suggested, that there is a proportional relationship between ‘entropy’ and ‘probability.’³⁷ In making this claim, Planck shows his complete conversion to the probabilistic-based understanding of entropy of Boltzmann while abandoning his own former position that entropy *always* increases in a closed system.

In this rather complex introduction to his paper, Planck thus introduces two metaphors with which he proposes to invent his theory of black body radiation. First, he associates the energy spectrum with entropy, thereby creating a metaphor ‘energy spectrum is an entropic phenomenon.’ Through this metaphor, Planck suggests that one can view electromagnetic energy in terms that are commonly used in thermodynamics. Indeed, this metaphor forms the basis of invention for his argument by inviting a quite novel perspective from which Planck could then reinterpret the behavior of heated black bodies from a thermodynamic point of view. He claims that this association between the ‘energy spectrum’ and ‘entropy’ will allow him to offer a

significance, that an analogy of denomination seemed to be helpful.” Quoted in Gillispie, *The Edge of Objectivity* 398.

³⁶ Planck, “On the Theory of the Energy Distribution Law of the Normal Spectrum” 82.

³⁷ Planck, “On the Theory of the Energy Distribution Law of the Normal Spectrum” 83.

“general interpretation” or theory of the energy spectrum and black body radiation. Planck then introduces a second metaphor ‘entropy is probabilistic’ when he argues that in order for one to see the energy spectrum in terms of thermodynamics, entropy must be viewed in terms associated with ‘probability.’ In other words, he adopts Boltzmann’s meaning for entropy, rather than its traditional meaning in classical physics.

These two metaphors, especially ‘energy is an entropic phenomena,’ more or less form the basis of invention for Planck’s theory of the energy spectrum and black body radiation. For Planck, to view the energy spectrum as an entropic phenomenon becomes highly significant as a way of interpreting and conceptualizing the behavior of black bodies. This metaphor thus changes his perspective in a way that allows him to view the black body phenomenon quite differently than he and others had before. Recognizing what Davidson calls “a novel or surprising likeness” between the two contrasting concepts, he embraces the metaphor and searches out its implications. However, in doing so, he establishes a broader contrastive relationship between the meanings typically associated with the energy spectrum and the meanings associated with thermodynamics. Interestingly, his audience, more than likely, would have assumed such a connection to be false, but Planck does not ask them to search out the implications of the metaphor for themselves. Instead, he himself interprets the implications of the metaphor for them, using the point of view offered by the metaphor as a means for inventing his theory. Indeed, for the most part, he hopes to show his audience that the ends (a working theory) justify the unorthodox use of concepts drawn from thermodynamics to reinterpret the black body phenomenon.

However, his use of another metaphor, Boltzmann’s ‘entropy is probabilistic,’ to create a new metaphor, ‘energy spectrum is an entropic phenomenon’ was most likely a confusing move for his audience, especially since most of them probably

dismissed Boltzmann's theories in the first place. In essence, Planck uses a newer metaphor to create another new metaphor, thus layering one interpretation onto another interpretation and increasing significantly the complexity of his argument. Perhaps a non-scientific example would best illustrate the problem that develops. Imagine someone states metaphorically that 'time is money' but then suggests that this metaphor is useful only if one also embraces the metaphor 'money is fire.' The layering of the metaphors complicates the interpretation considerably because the speaker would be asking the listener to hunt out the meaning of one metaphor through interpretations of another metaphor. And yet, when Planck claims that the 'energy spectrum is an entropic phenomenon' only if one accepts that 'entropy is probabilistic,' he creates this sort of higher level of complexity for his audience. In spite of this complication, though, Planck claims in his paper that only an acceptance of Boltzmann's understanding of entropy allows one to develop an explanation for the energy spectrum. This application, he claims, leads to "the clarity and uniqueness of the given prescription for the solution of the problem."³⁸

In the body of the paper, Planck brings forward two hypotheses that he claims are due to the relationship between Boltzmann's notion of entropy and the energy spectrum. These two hypotheses form the heart of the 1900 quantum paper. Supporting the first hypothesis, he derives a formulaic representation of the relationship between entropy and probability (something Boltzmann had not fully been able to do). The formula he derives is³⁹

³⁸ Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" 83.

³⁹ Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" 86. Boltzmann had argued that $S \propto \ln W$, but never derived the formula or developed the constant k which bears his name.

$$S = k \ln W$$

S is the entropy of the system

k is a constant (Boltzmann's constant)

W is the probability of that a particular state exists

This is essentially a formulaic expression for Boltzmann's metaphor 'entropy is probabilistic.' Plugging this relation into his October 1900 formula, Planck shows that the formulaic relationship between entropy and probability allows his October black body distribution law to calculate accurately the energy spectrum. Also, Planck illustrates, the relation allows him to derive the important constant k (called "Boltzmann's constant"). Arguing that the accurate derivation of this constant is proof of the absoluteness of his formula, Planck then claims that his use of thermodynamic concepts to interpret the energy spectrum offers a valid thermodynamic-based theory of black body radiation.⁴⁰

As he argues for the first hypothesis, though, Planck introduces a second hypothesis that he claims is brought about by the relationship between the energy spectrum and entropy. Planck shows, almost casually, that an acceptance of Boltzmann's relationship between entropy and probability also urges one to adopt the *discontinuity*, or atomism, that was the centerpiece of Boltzmann's atomistic thermodynamics.⁴¹ Reinforcing this point, Planck argues that the body of energy that makes up the energy spectrum must be divisible into "energy elements" or "discontinuous" quantities, much as a gas is divisible into atoms or molecules.⁴² Or, as this relationship between energy and discontinuity soon came to be known, energy is 'quantized.' Planck introduces this hypothesis in the following passage:

⁴⁰ Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" 87-88.

⁴¹ Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" 84.

⁴² Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" 84.

If E [Energy] is considered to be a continuously divisible quantity, this distribution is possible in infinitely many ways. We consider, however—this is the most essential point of the whole calculation—E to be composed of a very definite number of equal parts and use thereto the constant of nature $h = 6.55 \times 10^{-27}$ erg sec. This constant multiplied by the common frequency ν of the resonators gives us the energy element ϵ in erg, and dividing E by ϵ we get the number P of energy elements which must be divided over N resonators.

If the ratio is not an integer, we take for P an integer in the neighborhood.⁴³

What makes this passage extraordinary is that Planck almost naively associates energy with discontinuity, creating in his work a seemingly unnoticed new metaphor, ‘energy is discontinuous,’ that implies a fundamental violation of the classical belief in a continuum in nature. This unexpected ‘quantum metaphor’ comes about because Boltzmann’s entropy metaphor, which posits that systems are made up of atoms or discrete quantities, urges Planck to also assume that energy must now be viewed as discontinuous. Indeed, what we see is that the quantum metaphor more or less emerges *parenthetically* out of Planck’s broader argument for his theory of the energy spectrum. Nevertheless, there is clear evidence that Planck recognizes necessity of the ‘energy is discontinuous’ relation. He illustrates this recognition by unmistakably arguing for the discontinuous nature of energy when he expresses the formula for which this paper is famous. Planck states the fundamental equation of the quantum theory when he writes, “This constant [h] multiplied by the common frequency ν of the resonators gives us the energy element ϵ in erg.” The formulaic expression for this relation is the following:

⁴³ Planck, “On the Theory of the Energy Distribution Law of the Normal Spectrum” 84.

$$\epsilon = h\nu$$

ϵ is energy

h is "Planck's constant"

ν is the frequency of the electromagnetic radiation

The constant h in this relation forces one to view energy as divisible into discontinuous quantities of $h\nu$. The relation $\epsilon = h\nu$ is essentially a formulaic expression for the quantum metaphor 'energy is discontinuous.'

Interestingly, though, the stress and placement of this emergent 'quantum' metaphor, 'energy is discontinuous,' in Planck's paper seems to suggest that it was the result of a means to an end on Planck's part, not a proposed major theoretical change. Planck pays relatively little attention to the metaphor itself, and it is certainly not the focus of the paper. Kuhn, who offers one of the closest readings of Planck's works, even claims that the relation $\epsilon = h\nu$ was a mysterious "ad hoc" hypothesis, and that Planck's lack of emphasis on this "energy elements" hypothesis is evidence that he did not truly realize that he had proposed that energy is discontinuous.⁴⁴ Indeed, Kuhn's claim seems to be supported late in the paper by Planck's statement that the "core of the whole theory presented here" is that "The probability of any state is proportional to the number of corresponding complexions, or, in other words, any definite complexion is equally probable as any other complexion."⁴⁵ In this statement, Planck claims that his derivation of Boltzmann's relationship between entropy and probability is the main point of his theory. Clearly, as shown by this statement, Planck believes that the core of his theory is his derivation and usage of Boltzmann's relationship $S = k \ln W$ to explain the energy spectrum, not the quantum relationship $\epsilon = h\nu$. Indeed, the

⁴⁴ Kuhn, *Black-Body Theory and The Quantum Discontinuity* 108, viii.

⁴⁵ A complexion is a single state of the system in Boltzmann's thermodynamics. Planck, "On the Theory of the Energy Distribution Law of the Normal Spectrum" 87.

metaphor 'energy is discontinuous' is only, as Kuhn points out, an ad hoc and seemingly parenthetical part of Planck's overall argument.

To sum up at this point, in Planck's paper, one can observe the development of two important new metaphors in physics. The first new metaphor, 'energy spectrum is an entropic phenomenon' urges Planck to reconceptualize the energy spectrum in terms of another slightly older metaphor, Boltzmann's 'entropy is probabilistic.' Planck uses this first new metaphor to guide the invention of his argument, illustrating for the audience the valuable conclusions brought about when the energy spectrum is interpreted through concepts associated with thermodynamics. Recasting the energy spectrum in terms of Boltzmann's entropy metaphor, he associates the energy spectrum with a cluster of concepts that define Boltzmann's meaning of entropy like "probability," "equilibrium," "statistics," "randomly," "disorder," "complexions," and "stationary states." Planck's second new metaphor invites the audience to reconceptualize 'energy' through terms associated with 'discontinuity' because, as Planck implies, an acceptance of Boltzmann's entropy metaphor urges one to assume that the energy spectrum is made up of discrete energy elements. As Planck recognizes, the presumption of atomism that is the basis Boltzmann's theory of thermodynamics urges a redefinition of energy into atomistic or discontinuous terms. Therefore, he discusses energy through a cluster of atomistic terms like "discrete," "energy elements," "integer," "equal parts," "independent," and "complexions."

Two Metaphors, Two Roles

Let us now return to our mystery about the origin of the quantum theory. When one reads Planck's 1900 quantum paper, it seems rather obvious, as Kuhn points out in great detail, that Planck did not fully discern the importance of his quantum relation $\epsilon = h\nu$. However, considering Planck's reinterpretation of the meaning energy into terms like "energy elements," and "integer" and his use of metaphorical phrases like

“[The total Energy is] to be composed of a very definite number of equal parts,” it seems equally obvious that he *did* develop some sort of discontinuous, or quantum, meaning for energy. Planck was, as Born claimed, perfectly clear that the relation $\epsilon = h\nu$ is important when he claimed that it represented “the most essential point of the whole calculation.”⁴⁶ However, he also obviously did not see it as the most important part of the paper. It seems as though both Born and Kuhn are right and wrong in some measure.

I believe metaphorical analysis allows us to illuminate Planck’s work in a way that avoids this ‘discovery’ debate between the ‘he did’ and ‘he did not’ factions represented by Born and Kuhn. What we find is that the two significant metaphors in his argument, ‘energy spectrum is an entropic phenomenon’ and ‘energy is discontinuous,’ play two quite different roles in his argument. The first, in which he reinterprets the behavior black body radiation through thermodynamics, serves as a sort of lens through which Planck interprets the black body phenomenon from a different perspective or point of view. He then uses this metaphor as a basis for the invention of his theory of the energy spectrum. The second metaphor, the quantum metaphor, however, seems to emerge naturally out of the invention of his theory. Indeed, for Planck, the notion that ‘energy is discontinuous’ is at best an unseen metaphor that he uses more as an obvious statement of fact rather than a claim that brings two concepts into contrast. Let us look more closely at how each of these metaphors is used in Planck’s argument.

The Invention of the Argument

In the last chapter, I suggested that new metaphors often urge scientists to embrace new ways of interpreting their physical and social situations, including natural

⁴⁶ Planck, “On the Theory of the Energy Distribution Law of the Normal Spectrum” 84.

phenomena. When one comes across a metaphor, it urges one to hunt out the possible implications of the metaphoric contrast between the two or more concepts involved, seeking potential meanings within the immediate rhetorical situation. And yet, the metaphor itself only provides a perspective from which one can then develop an argument. It is not the argument itself. Therefore, an interpreter uses the metaphor as the basis of an argument, allowing the metaphor to, as Rorty states, “change one’s language and one’s life... rather than systematize either.”⁴⁷

In Planck’s work, we see that he used his ‘energy spectrum is an entropic phenomenon’ metaphor as a basis for inventing the argument in his 1900 quantum paper. The metaphor created the perspective from which he reconceptualized and reinterpreted the black body problem; meanwhile it also established a contrastive relationship between the energy spectrum and entropy that contained likenesses he was urged to resolve. Therefore, Planck became the interpreter of a metaphor that he himself invented. Exploring the implications of the metaphor, he used it to recast the black body phenomenon into thermodynamic terms, showing how the likenesses between the energy spectrum and entropy led to a broader understanding of the black body phenomenon. This metaphor, however, was not a particularly new one for Planck by December 1900. For a few years he had already been using ‘energy spectrum is an entropic phenomenon’ to interpret the black body phenomenon. Indeed, many of his papers from 1897 to 1900 were developed through applications of concepts from thermodynamics, especially entropy, to explain the energy spectrum. During this time period, the metaphor urged Planck to embrace a quite different perspective toward the energy spectrum phenomenon than the perspectives with which other scientists

⁴⁷ Rorty, *Essays on Heidegger and Others* 13.

interpreted the black body phenomenon. Reflecting this difference in perspective between himself and other scientists, Planck writes in his autobiography,

While a host of outstanding physicists worked on the problem of spectral energy distribution, both from the experimental and theoretical aspect, every one of them directed his efforts solely toward exhibiting the dependence of the intensity of the radiation on the temperature [using Maxwell's theories]. . . . As the significance of the concept of entropy had not yet come to be fully appreciated, nobody paid any attention to the method adopted by me, and I could work out my calculations completely at my leisure, with absolute thoroughness, without fear of interference or competition.⁴⁸

His interpretation of this new metaphor urged him to approach the black body problem from a quite different perspective than Maxwell's theories of electromagnetism would have supported. Nevertheless, with each successful application of the metaphor toward interpreting the black body phenomenon from 1897 to 1900, he became further convinced of its usefulness. In a sense, it 'turned' his rational account (*logos*) of the black body phenomenon so that he began to conceptualize and talk about the energy spectrum quite differently than he had before.

It was, however, only when he embraced the 'entropy is probabilistic' metaphor that he could then invent the argument in his December 1900 quantum paper. He had "until then not bothered about the connection between entropy and probability," but he found it to be the only way in which his October 1900 formula could account for the data offered by Rubens and Kurlbaum.⁴⁹ This final turn was a crucial one, and a very difficult one for Planck to make. Convinced that his formula represented an

⁴⁸ Planck, *Scientific Autobiography* 38.

⁴⁹ Planck, *Scientific Autobiography* 37.

absolute, however, he used the ‘entropy is probabilistic’ metaphor to reinvent many his previous assumptions about black body radiation and even his beliefs about thermodynamics in general. In a letter, he wrote,

I had been wrestling unsuccessfully for six years (since 1894) with the problem of equilibrium between radiation and matter and I knew that this problem was of fundamental importance to physics; I also knew the formula that expresses the energy distribution in normal spectra. A theoretical interpretation therefore *had* to be found at any cost, no matter how high. . . I was ready to sacrifice every one of my previous convictions about physical laws.⁵⁰

In fact, this sacrifice of some of his dearest beliefs is exactly what happened when he adopted the perspective offered by Boltzmann’s ‘entropy is probabilistic’ metaphor. Realizing that his own beliefs were not consistent with his formula, he came to see the situation from Boltzmann’s point of view. By abandoning his own long-held beliefs about entropy and adopting Boltzmann’s metaphorical relationship between entropy and probability, he could then invent a working argument that explained the energy spectrum.

Indeed, throughout the short history of the development of his theory of the black body phenomenon, we observe that Planck reinterpreted and adapted his rational account (*logos*) in order to shape his explanations of the energy spectrum to fit his physical and social situation. The development of the theory itself was an effort that required him to be continually returning to the ‘energy spectrum is an entropic phenomenon’ metaphor for guidance, seeking out possible courses through which he could develop a working theory. In the early stages of his efforts, he applied his rather “classical” beliefs from thermodynamics—advocated by the broader scientific

⁵⁰ Planck letter to Robert Williams Wood. Quoted in Hermann, *The Genesis of Quantum Theory* 23.

community—toward reinterpreting the concept of the energy spectrum. But then in 1900, when Rubens and Kurlbaum's new physical data called his original theories into question, he adapted his argument to his rhetorical situation by accepting Boltzmann's arguments for atomism and probability. Thus, he altered and shaped his beliefs throughout the invention process, maintaining the perspective offered by the metaphor while changing his previous beliefs in its wake.

I find it interesting that there is little evidence that the metaphor 'energy spectrum is an entropic phenomenon' or 'entropy is probabilistic' themselves *caused* any sort of shift that one might call a change in Planck's "paradigm" or "schema." Rather, Planck gradually adjusted his beliefs, language, and understanding of the black body phenomenon, using these two metaphors to ultimately invent a theory that appropriately described the data available. Indeed, considering Planck's thorough background in thermodynamics, it would have been only natural that he would be inclined to interpret most problems from a perspective offered by a theoretical context from thermodynamics. In fact, Planck's papers on black body radiation that preceded the 1900 quantum paper were all consistent with his overall rational account of nature in which his beliefs about thermodynamics played a significant role. Only in the final December 1900 paper did he show a significant change in beliefs by adopting Boltzmann's 'entropy is probabilistic' metaphor. However, even as he embraced Boltzmann's metaphor, he still preserved the greater body of his interpretation of black body radiation and his beliefs about physics in general. Instead of a paradigm shift, I believe we observe in Planck's work a gradual change in his rational account (*logos*) of nature due to his interpretations of the metaphors, 'energy spectrum is an entropic phenomenon' and 'entropy is probabilistic.' This change was situated into a broader physical and social rhetorical context in which Planck was immersed.

In the case of the ‘energy spectrum is an entropic phenomenon’ metaphor, I believe we see the way in which metaphors invite ‘turns’ in scientists’ rational accounts (*logos*) of nature and thus serve as the basis for the invention of scientific discourse. Each metaphor that Planck either created or accepted urged him to change his rational account and thus think and talk about the energy spectrum in a different way. The metaphorical relationship between the energy spectrum and entropy, therefore, became the basis of Planck’s *logos* of the black body radiation problem. The metaphor created a perspective that he accepted, and it formed the basis of invention for his 1900 quantum paper.

The Emergence of a New Dominant Metaphor

Perhaps of more interest—though less important to the invention of Planck’s argument—the ‘energy is discontinuous’ metaphor plays a rather marginal role in the 1900 quantum paper. Indeed, it is noteworthy that this metaphor did *not* serve as the basis for the invention of Planck’s argument. If anything, the quantum metaphor emerged rather innocuously as a parenthetical outcome of the development of his theory of the energy spectrum. Nevertheless, the metaphor was created quite naturally because Planck had already embraced a point of view (Boltzmann’s thermodynamics) that urged him to reinterpret many of his former beliefs into terms associated with atomism. Whether or not Planck realized the importance of his new metaphor is really unimportant and, frankly, not something we could determine anyway. What *is* important is that the metaphor emerged in a very clear and undeniable form, because Planck’s usage of the metaphor ‘energy spectrum is an entropic phenomenon’—altered by Boltzmann’s atomism—invited him to change his rational account of the black body phenomenon in a way that implied discontinuity. Indeed, his *logos* had been so ‘turned’ by the central metaphor of his argument that the so-called quantum postulate must have seemed like a natural consequence of his overall argument. Planck,

therefore, more or less states 'energy is discontinuous' as an obvious fact, not a questionable assertion.

As discussed in the last chapter, Bohm and Peat refer to this sort of creative act as the result of "metaphorical play" in which new metaphors, and thus new perspectives, are created when scientists bring different concepts into contrastive relationships.⁵¹ Bohm and Peat argue that these metaphorical relationships are the basis of creativity in science because metaphors emerge out of the activity of doing science itself. As such, without fanfare, Planck reinterpreted the meaning of 'energy' to be consistent with his changed *logos*, or rational account, of the black body phenomenon. While developing his argument, he reinvented the traditional "continuous" account of energy by associating energy with atomistic or discontinuous terms. Indeed, once he had accepted Boltzmann's atomistic thermodynamics, the discontinuous nature of energy probably seemed like an obvious consequence of his argument, not a radical new concept. Therefore, the obviousness of the connection between energy and discontinuity is most likely the reason why Planck did not address this argument further in his December 14, 1900 paper.

The reason I have singled this metaphor out for discussion, of course, is because it eventually became a dominant metaphor in modern physics, not because it is the focus of Planck's paper. In his argument, the quantum metaphor takes on an embryonic quality, almost unseen within the argument that Planck wanted to make. In *Permanence and Change*, Burke suggests that a metaphor has a way of "revealing hitherto unsuspected connectives" between concepts.⁵² Indeed, it appears as though Planck's interpretation of the metaphors 'energy spectrum is an entropic phenomenon'

⁵¹ Bohm and Peat, *Science, Order, and Creativity* 48-52.

⁵² Burke, *Permanence and Change* 90.

and ‘entropy is probabilistic’ urged the quantum metaphor forward as one of these “unsuspected connectives.” It was after Einstein interpreted the quantum metaphor in Planck’s 1900 quantum paper that it was initially used to develop a dramatically new way of conceptualizing reality. Two decades later, this metaphor could be considered the dominant metaphor of modern physics. In Planck’s paper, however, the quantum metaphor plays only a marginal role.

Conclusions

In this chapter, I have used metaphorical analysis to illustrate the emergence of the quantum hypothesis in Planck’s 1900 quantum paper. We see that the interpretation of metaphors often urge a turn in one’s rational account in subtle ways. Planck’s ‘energy spectrum is an entropic phenomenon’ metaphor urged him to propose the absurd, ‘energy is discontinuous.’ And, even he expressed a distaste for the discontinuity brought about by the quantum postulate. In 1915, he wrote to Paul Ehrenfest that “For my part, I hate discontinuity of energy even more than discontinuity of emission.”⁵³

If so, how does conceptual change in science occur when one of the instigators of change does not recognize or even rejects the results of his arguments? Ironically, this situation occurs frequently in the history of science. One scientist develops a metaphor that other scientists interpret in new ways that might not have be apparent to the metaphor’s originator. These other scientists then embrace the perspective urged by the new metaphor and begin to see known phenomena from a different point of view. In the case of the quantum metaphor, it was not noticed until 1905 and did not gain widespread recognition until 1908.⁵⁴ As we will see in the next chapter, Einstein

⁵³ Quoted in Holton, *Thematic Origins of Scientific Thought* 158.

⁵⁴ Kuhn, *Black-Body Theory and The Quantum Discontinuity* 144.

interpreted the meaning of the quantum metaphor far more broadly than Planck would have anticipated. Einstein's interpretation of the quantum metaphor urged him to rethink his beliefs about light, thus creating the notion of "light quanta." Planck, ironically, became one of the most significant detractors of Einstein's new quantum interpretation of light.

**CHAPTER FOUR
METAPHOR AND INTERPRETATION:
ALBERT EINSTEIN'S NEW PERSPECTIVE**

All these fifty years of conscious brooding have brought me no nearer to the answer to the question "What are light quanta?" Nowadays every Tom, Dick, and Harry thinks he knows it, but he is mistaken.

Albert Einstein

Though one might say that Planck developed the 'energy is discontinuous' metaphor, or 'energy quanta,' that became the centerpiece of the quantum theory, it was only when Einstein, an unknown patent clerk at the time, explored the likenesses and contrasts implied by the 'quantum' metaphor that it came into its own. Unlike Planck, Einstein understood that the quantum postulate need not be restricted to energy alone but could be used to interpret other phenomena.¹ In his "1905 light quanta" paper, "Concerning a Heuristic Point of View about the Creation and Transformation of Light,"² Einstein wrote, "We wish to demonstrate in what follows that Planck's derivation of the elementary quanta is to a certain degree independent of his theory of 'black radiation.'"³ Indeed, it is in this passage that we see one of the first, if not the first, unqualified expressions of a 'quantum' perspective of nature. Of Einstein's 1905 light quanta paper, Kuhn writes "In a sense, it announces the birth of the quantum theory."⁴

¹ Jeremy Bernstein, *Einstein* (New York, Viking Press, 1973) 192.

² Albert Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light," *Annalen der Physik* 17 (1905): 132-148. Translation in H.A. Boorse and L. Motz, eds., *The World of the Atom* (New York: Basic Books, 1966) 544-557.

³ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 547.

⁴ Kuhn, *Black Body Theory and the Quantum Discontinuity* 170.

Ironically, Planck, who was by then editor of *Annalen der Physik* in which the light quanta paper appeared, was unconvinced by Einstein's argument until years later. Even as late as 1913 in a recommendation for Einstein for membership in the Royal Prussian Academy of Sciences, Planck apologetically stated, "That he may sometimes have missed the target in his speculations, as, for example, in his hypothesis of light quanta, cannot really be held against him."⁵ Planck, as mentioned before, believed that the discontinuity implied by his quantum metaphor would prove to be a mathematical means to an end. He then spent years unsuccessfully attempting to reconcile it with classical physics. Einstein, however, embraced the concept of energy quanta with enthusiasm. He wrote to his friend Konrad Habicht in 1905, "I promise you four papers in exchange [for your thesis]... the first... is very revolutionary."⁶ Interestingly, the 'revolutionary' paper he was referring to was his article on light quanta, not his famous article on special relativity that was also among these four.⁷ Published later in 1905, the light quanta paper contained a rather novel explanation of electromagnetic radiation that introduced a 'corpuscular,' or quantum, interpretation of the behavior of light. For much of his life, Einstein pondered the question of light quanta, and it was his work on light quanta and the "photoelectric effect" that won him the Nobel Prize in 1922.⁸

⁵ Quoted in Bernstein, *A Comprehensible World* 120.

⁶ Banesh Hoffman, *Albert Einstein: Creator and Rebel* (New York, Plume, 1972).

⁷ Hoffman, *Albert Einstein: Creator and Rebel* 43.

⁸ Many people mistakenly assume that Einstein received the Nobel Prize for his theories of Relativity. He actually received it for his work on the Quantum Theory of Light. However, the circumstances surrounding the award were mysterious. Much has been made about the peculiarity of the announcement of the Nobel Prize for Einstein. The wording from the Nobel committee went as follows: The prize "is awarded to the person within the field of physics who has made the most important discovery or invention/to Albert Einstein being most highly deserving in the field of theoretical physics, particularly for his discovery of the law pertaining to the photoelectric effect." Quoted in Bernstein, *A Comprehensible World*. The photoelectric effect was a minor part of Einstein's body of work by 1922 which included all his great works on Relativity and Quantum

In this chapter, I will show how new metaphors in science urge scientists to reinterpret their beliefs and invent new arguments. When one analyzes the metaphors in Einstein's 1905 light quanta paper, it becomes obvious that he interpreted the implications of Planck's quantum metaphor far more broadly than Planck would have allowed. This act of interpreting the quantum metaphor, 'energy is discontinuous,' I will show, invited Einstein to change his perspective and come to see the phenomenon of light from a different point of view. In other words, the quantum metaphor urged a 'turn' in Einstein's rational account in such a way that a belief in light quanta became for him a necessary consequence of Planck's metaphor.

Rhetorical Situation

The rhetorical situation of Einstein's brilliant scientific works of 1905 is probably best revealed by considering the young Einstein himself. His life is as paradoxical as his work. In 1905, after a few frustrating attempts to receive his doctorate, Einstein took a position as a "Technical Expert" at the Swiss Patent Office in Bern. Though he had published a few interesting papers on statistical thermodynamics from 1902 to 1904, he was at age 26 an unknown in the field of physics who was unable to find an academic position. Einstein's understanding of physics was mostly self-taught, because he was unsatisfied by the content of his courses at the Zurich Polytechnic Institute. During this time, he began to study on his own the works of Maxwell, Mach, Hertz, Boltzmann, and Lorentz.⁹ In doing so, he developed a great respect and mastery of Maxwell's equations and electromagnetic theory of light. Also, he was inspired by the statistical, or probabilistic, approach to thermodynamics that he

Theories of Light. Some historians believe the committee decided that Einstein deserved the Prize for his overall work but did not want to award it based on the still controversial theory of relativity.

⁹ Holton, *Thematic Origins of Scientific Thought* 214.

had learned from reading Boltzmann's *Gas Theory*.¹⁰ Moreover, he strongly believed and advocated Mach's positivist empiricist philosophies of science which stressed the use of "observable" and non-metaphysical evidence to develop theories.

Recognition of these important themes in Einstein's beliefs is critical, because it is sometimes hard to regard him as anyone other than the consummate theoretical physicist. But to gain an understanding of his early work, one should first recognize that his way of approaching physics changed dramatically over the course of his life. Holton, who is probably the most thorough historian of Einstein's work, claims that Einstein's life can be understood as "a pilgrimage from a philosophy of science in which sensationism and empiricism were at the center to one in which the basis was a rational realism."¹¹ Indeed, as a young physicist in 1905, Einstein saw himself as an experimentalist and a strict empiricist who spurned any scientific argument not based on observables.¹² Only two decades later, though, Einstein's view of science was quite different. Illustrating this change, Werner Heisenberg recalled that in 1926 he mentioned to Einstein that all quantities should be defined as "observables," to which Einstein replied "But you don't seriously believe that none but observable magnitudes must go into a physical theory?" Taken aback by this renunciation of strict empiricism, Heisenberg then pointed out to Einstein that his theory of relativity—in which Einstein used a discussion of clocks and rods to redefine Newton's metaphysical definitions of absolute time and space—succeeded because it relied purely on observable means. To which an older Einstein replied,

¹⁰ M.J. Klein, "Thermodynamics in Einstein's Thought," *Science* 157 (1967) 509-516.

¹¹ Holton, *Thematic Origins of Scientific Thought* 237.

¹² Anton Reiser, *Albert Einstein* (New York: Boni, 1930) 52.

Possibly I did use this kind of reasoning but it is nonsense all the same. . . . But on principle, it is quite wrong to try founding a theory on observable magnitudes alone. In reality the very opposite happens. It is the theory which decides what we can observe.¹³

In 1905, Einstein would have probably replied to Heisenberg's assertion quite differently. At that time, he was highly persuaded by the positivist empiricist movement in German science, especially as expressed by Mach.¹⁴ In his *Autobiographical Notes*, Einstein reported that he was "profoundly influenced" by Mach's *The Science of Mechanics* (1897).¹⁵ In this text, Mach offered a comprehensive treatise on positivist empiricism that challenged Newton's *Principia* on philosophical grounds. Mach argued that all human comprehension of nature is based solely on sensations; therefore, 'metaphysical' concepts such as absolute time and space needed to be eliminated from science, because they presumed incorrectly that a hidden reality exists beneath sensation.¹⁶ Because absolute time and space played a central role in Newton's theories, Mach disputed that mechanics must be the foundation of scientific knowledge as many nineteenth-century physicists assumed.¹⁷

As a self-professed Machian himself, the younger Einstein was skeptical of what Mach often called "scientific dogma." He was therefore, both fascinated by and critical of Maxwell's theory of light. Maxwell in the middle nineteenth-century had

¹³ Werner Heisenberg, *Physics and Beyond: Encounters and Conversations* (New York: Harper and Row, 1971) 63.

¹⁴ Gerald Holton's brilliant essay "Mach, Einstein, and the Search for Reality" argues this point in great detail. See Holton, *Thematic Origins of Scientific Thought* 237-277.

¹⁵ Einstein, *Autobiographical Notes* (Lasalle, Ill.: Open Court, 1979) 21.

¹⁶ Hoffman, *Albert Einstein: Creator and Rebel* 78

¹⁷ This summary is paraphrased from Holton, *Thematic Origins of Scientific Thought* 239-240.

proven rather conclusively that light is an ‘electromagnetic’ wave that travels through an omnipresent medium called ‘aether.’¹⁸ His theories were especially important because he developed a set of equations that linked the disparate scientific studies of light, electricity, and magnetism into one unified theory of electromagnetism. By Einstein’s day, physicists were as sure of Maxwell’s theory of light as today’s scientists are of the theory of relativity. Einstein, too, was convinced of the formulaic aspects of Maxwell’s theories; but he was troubled by one aspect of Maxwell’s theories that he could not resolve.¹⁹ He asked himself what a wave of light would look like if an observer were traveling alongside it at the speed of light. To such an observer, Einstein reasoned, the wave pattern of light would seem to disappear. The problem, as physicist Jeremy Bernstein writes, is that

the Maxwell equations... do not provide for such a possibility, and hence either *they must be wrong or it must not be possible for a material observer to move with the speed of light*. From the point of view of classical physics either alternative seemed absurd.²⁰

Thus, through interpreting this simple thought experiment, Einstein concluded that there was something fundamentally wrong with Maxwell’s wave theory of light, even if the equations at its core worked. Einstein resolved the speed of light issue in his 1905 paper on special relativity—something we will not discuss here—but his 1905 light quanta paper was also developed in part to answer the question of what light “looks like” if it cannot be a wave. More than likely, the notion of ‘light waves’ in Maxwell’s

¹⁸ Gillespie, *The Edge of Objectivity* 473. The need for a medium like the aether was assumed because wave-like phenomena, like water-waves or sound, require some medium, like water or air, to carry them. It was assumed therefore, that light as a wave would have an almost undetectable medium in which it travelled. Einstein in his 1905 Special Relativity paper denied that an aether exists.

¹⁹ Bernstein, *Einstein* 38.

²⁰ Bernstein, *Einstein* 38.

theories struck Einstein as yet another unobservable, metaphysical construct that went against Mach's empiricist principles.

Nonetheless, the seemingly flawless success in application of Maxwell's equations had already conferred on them by 1905 the status of certainty in the scientific community. Even strict empiricists had been won over to Maxwell's theory when, in the 1880s, German physicist Heinrich Hertz confirmed Maxwell's equations—and by association his theory—by generating electromagnetic radio waves and showing that they quantifiably exhibited the wave-like behavior specified by Maxwell.²¹ However, as Hertz was conducting his experiments to confirm electromagnetic waves, he identified a strange, unexplainable phenomenon that soon became known as the 'photoelectric effect.' Put simply, the photoelectric effect occurs when light strikes a metal surface, inducing what are now called 'electrons' to be emitted from the metal. By itself, the photoelectric effect did not call Maxwell's theory of light into question, but attempts to explain it through wave function equations continued to fail. In 1902, Philipp Lenard added to the mystery by showing that the velocity of the electrons released from the metal did not depend on the *intensity* of the light, only on its *frequency* (color).²² Lenard's results seemed to contradict Maxwell's theories, which suggested that light of more intensity (more waves and thus more energy) should cause each electron to be emitted at a higher velocity. Moreover, the frequency of the light, according to Maxwell's theories, should not have been relevant to the velocity of the electrons at all. Against all expectations, Lenard showed that frequency was relevant and intensity was not. When Einstein's 1905 light quanta paper is analyzed later in this chapter, we will return to the photoelectric effect.

²¹ Gillispie, *The Edge of Objectivity* 493-494.

²² Friedrich Hund, *The History of Quantum Theory* (London: Harrap, 1974) 43.

Finally, despite Mach's polemics against atomism, Einstein was persuaded by the statistical thermodynamics of Boltzmann in which atomism played a prominent part. Kuhn writes that "Einstein... began instead to develop a statistical thermodynamics applicable not only to gases, the main concern of earlier workers, but to other states of aggregation as well."²³ By 1905, he had published three papers on statistical thermodynamics in which he enhanced Boltzmann's probabilistic theories of phenomena at the molecular level. During this period, he began to view matter as essentially atomistic, and in 1905 Einstein published his theory of "Brownian motion" which offered some of the first phenomenological evidence for the existence of atoms and molecules. Of Einstein's work in thermodynamics, Kuhn writes,

That Einstein nevertheless felt the need to go farther is an example of his extraordinary ability to discover and explore problematic interrelationships between what others took to be merely factual generalizations about natural phenomena.²⁴

The same could also be said of all three of Einstein's 1905 papers.

To sum up at this point, it is important to recognize a few important contextual themes in Einstein's early work. First, he preferred to develop his arguments through 'observable' means of measurement rather than metaphysical ones. For example, his use of clocks and rods to discuss time and space were attempts to employ only observable means of measurement that avoided Newton's metaphysical understandings of absolute time and space. Second, all his arguments were grounded on the results of empirical 'events' or experiments, real or conceptual, rather than on scientific laws or principles.²⁵ This Machian focus on observable evidence often encouraged him to

²³ Kuhn, *Black Body Radiation and Quantum Discontinuity* 171.

²⁴ Kuhn, *Black Body Radiation and Quantum Discontinuity* 176.

²⁵ Holton, *Thematic Origins of Scientific Thought* 242.

challenge “dogmatic” theoretical frameworks with little hesitation, especially theories that relied on metaphysical constructs like those of Newton and Maxwell. Third, he was persuaded by atomic theories of matter, and, like Planck, accepted Boltzmann’s thermodynamics. This background in statistical thermodynamics would have made Planck’s 1900 quantum paper readable and of particular interest to Einstein. Finally, as a young, little-known physicist, he showed a cavalier attitude toward scientific formalism and was eager to apply new and untested beliefs to long-studied phenomena. This willingness and ability to transgress scientific orthodoxy showed up consistently in his reinterpretations of basic concepts from physics (e.g. time, space, simultaneity, light) that were assumed to have formal, stable, and seemingly unquestionable meanings.

Einstein’s 1905 Light Quanta Paper

Einstein’s interpretation and expression of Planck’s quantum metaphor in the 1905 light quanta paper, “Concerning a Heuristic Point of View about the Creation and Transformation of Light,” reflects many of the contextual themes just discussed. The paper itself is perhaps best known for two reasons. First, it introduced the concept of ‘light quanta,’ which later took on the label ‘photons.’ Second, it offered an explanation of the photoelectric effect that eventually won Einstein his Nobel Prize. More important, though, the paper interpreted Planck’s concept of ‘energy quanta’ in a way that offered a fundamental challenge to Maxwell’s theory of electromagnetic radiation. The paper also illustrated the first use of the quantum metaphor to describe a phenomena other than black body radiation, suggesting that the quantum metaphor could be used to interpret other aspects of nature.

As in the introductions of his other famous 1905 papers on relativity and Brownian motion, Einstein begins his light quanta paper by calling the readers’

attention to a conflict or incongruity in the body of scientific beliefs.²⁶ Einstein writes, “There is a profound formal difference between the theoretical representations of gases and other ponderable bodies which physicists have constructed and Maxwell’s theory of electromagnetic processes in so-called empty space.”²⁷ The incongruity Einstein identifies is the difference between the ‘discontinuous’ theories of particles (gas molecules, atoms, electrons) and ‘continuous’ theories of waves (light, x-rays, aether). In other words, Einstein points out that particle descriptions of gases, represented by atomic thermodynamics, are conceptually incompatible with the wave descriptions of electromagnetic radiation, represented by Maxwell’s equations of light.

In making this seemingly obvious distinction for his readers, Einstein simply restates the contrastive relationship between electromagnetism and thermodynamics that was originally created by Planck’s 1900 metaphor ‘energy spectrum is an entropic phenomenon.’ Unlike Planck, though, Einstein more critically explores the implications of this metaphoric relationship by stressing the fundamental differences between continuous (electromagnetism) and discontinuous (thermodynamics) accounts of phenomena. Specifically, he points out that in theories of electromagnetism, or light, “energy must be considered a continuous spatial function.”²⁸ In other words, as a wave-like phenomenon, light must distribute its energy “continuously throughout an ever-increasing volume of space.”²⁹ Quite the opposite, Einstein points out, a volume of particles—say a confined group of gas molecules—has a collective energy that “can

²⁶ Holton, *Thematic Origins of Scientific Thought* 193.

²⁷ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 544.

²⁸ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 544.

²⁹ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 544.

break up into arbitrarily many, arbitrarily small parts.”³⁰ Therefore, unlike light, a system of particles distributes energy discontinuously in space.

Essentially, by developing this simple but fundamental contrast, Einstein points out to the readers that energy takes on two seemingly contradictory meanings ‘energy is continuous’ and ‘energy is discontinuous’ that depend on whether one is talking about the energy of waves or the energy of particles. In other words, Einstein illustrates for his readers that the meaning of energy is supported by two irreconcilable metaphors: either ‘energy is continuous’ as in a wave or ‘energy is discontinuous’ as in a system of particles. Indeed, these paradoxical meanings for ‘energy,’ identified by Einstein, are significant because they suggest completely opposite interpretations of nature that posit either continuity or discontinuity. By stressing the opposition between these two “heuristic points of view,” Einstein draws the readers into his argument by illustrating the paradoxical meaning of energy in rather simple terms. This approach was common to all three of Einstein’s major 1905 papers. Holton writes, “Each begins with a statement of formal asymmetries or other incongruities of a predominantly aesthetic nature (rather than, for example, a puzzle posed by unexplained experimental facts).”³¹ Interestingly, the asymmetry or incongruity that Einstein addresses in the 1905 light quanta paper is quite simply brought about by his recognition that physics community relies on two incompatible metaphors (continuous and discontinuous) to describe the energy phenomenon.

Having established an intriguing problem in physics, at the end of his introduction to the 1905 light quanta paper Einstein identifies the problem he will address in the rest of the article. He writes,

³⁰ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 544.

³¹ Holton, *Thematic Origins of Scientific Thought* 193.

in spite of the complete experimental verification of the theory of diffraction, reflection, refraction, dispersion, and so on, that the theory of light that operates with continuous spatial functions may lead to contradictions with observations if we apply it to the phenomena of the generation and transformation of light.³²

In other words, Einstein suggests to his readers that, despite the success of Maxwell's wave theory of light, in some cases they contradict experimental observations. To solve this problem, Einstein then develops a new metaphor, 'light is quantized,' that he believes will resolve the contradictions between theory and experiment. He writes,

It appears to me, in fact, that the observations on "black-body radiation," photoluminescence, the generation of cathode rays with ultraviolet radiation [the photoelectric effect], and other groups of phenomena related to the generation and transformation of *light can be understood better on the assumption that energy in light is distributed discontinuously in space*. According to the presently proposed assumption the energy in a beam of light emanating from a point source is not distributed continuously over larger and larger volumes of space, which move without subdividing and which are absorbed and emitted only as units [*Italics mine*].³³

In this passage, Einstein clearly states for his readers the basis of his new "heuristic point of view" concerning light. Though he does not mention Planck at this point, Einstein employs Planck's 'energy is discontinuous' metaphor and suggests that one can then use it to explain light in discontinuous terms. Indeed, with little hesitation, Einstein in this passage suggests that if one accepts Planck's quantum metaphor, then

³² Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 544-545.

³³ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 545.

one is urged to also accept the notion that light is discontinuous, or quantized. In making this claim, he clearly interprets Planck's quantum metaphor more broadly and uses it as a focal point of his argument. Whereas Planck may not have fully considered the implications of his claim that energy is made up of "a very definite number of equal parts," Einstein sees it as a starting place for reinterpreting phenomena associated with energy. Or, in other words, the metaphor 'energy is discontinuous' serves as the basis of invention for Einstein's argument concerning the behavior of light.

Einstein begins the body of his paper by stating rather directly that "We wish to demonstrate in what follows that Planck's derivation of the elementary quanta is to a certain degree independent of his theory of 'black radiation.'"³⁴ To prove to his readers that the concept of quanta is independent of black body radiation, Einstein uses Planck's notion of energy quanta to calculate the mass of a hydrogen atom—a seemingly unrelated phenomenon to black body radiation. It is here where he most clearly signals his willingness interpret the quantum metaphor beyond the limited role that it played in Planck's paper. Einstein uses his calculation of the mass of the hydrogen atom to disassociate the quantum metaphor from Planck's explanation of the black body phenomenon. This strategy is important because it then allows Einstein to suggest to his readers that the quantum metaphor creates a new point of view that is independent of Planck's argument, thus opening the door for applications to other phenomena.

Securing the independence of the quantum metaphor, Einstein then goes on to argue that Planck's application of concepts from Boltzmann's statistical thermodynamics to explain the energy spectrum calls for a redefinition of light into atomistic terms. He argues that in order for Planck's formula to legitimately use

³⁴ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 547.

concepts from thermodynamics, light would need to be treated as a gas-like entity made up of individual particles. Einstein writes, “The entropy of monochromatic radiation [light] of sufficiently small density varies with volume like the entropy of an ideal gas.”³⁵ Or, to generalize, Einstein here implies that Planck’s quantum metaphor suggests that light is made up of particles. Therefore, the entropy of a quantity of light, made up of light quanta, varies much like the entropy of a quantity of ideal gas, made up of atoms. Indeed, this implication was one that Planck only indirectly recognized in his 1900 quantum paper. Planck had implied that the use of Boltzmann’s thermodynamics suggested that energy must be viewed as discontinuous, but for some reason he was not prepared to see energy fully in discrete terms. As such, the idea that the energy spectrum was made up of small corpuscles of light, not waves, was completely foreign to Planck.

Let us regroup at this point. In the body of his paper, Einstein pursues two rhetorical strategies in which metaphors play a central role in inventing his argument. First, he shows that Planck’s metaphor, ‘energy is discontinuous,’ can be applied to areas of physics other than studies of black body radiation. Planck’s quantum metaphor, therefore, forms the basis of the invention of Einstein’s new ‘heuristic point of view’ concerning light. Einstein’s second strategy is more subtle, but it affirms his reinterpretation of the meaning of light. He points out that one cannot use beliefs—as Planck had—from atomistic thermodynamics without also accepting the broader set of beliefs that go along with them. By using Boltzmann’s formulas to solve the black body radiation problem, Planck had implied that the radiation or light that made up the energy spectrum must be redefined in particle terms. Einstein merely points out this fact and uses it as further evidence that his light quanta argument is valid. Planck certainly

³⁵ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 550.

never expected this application of his new quantum metaphor; but as Burke says, “the metaphor always has about it precisely this revealing of hitherto unsuspected connectives.” Einstein’s light quanta metaphor is the result of one of these unsuspected connectives. His light quanta hypothesis suggests that light is corpuscular, like atoms, rather than strictly wave-like. Indeed, it is at this point that Einstein interprets Planck’s quantum metaphor far beyond its usage in the 1900 quantum paper.

Late in the paper, after reviewing Boltzmann’s relation of probability and entropy (as developed by Planck), Einstein directly applies formulas from thermodynamics to light, illustrating the corpuscular nature of light. He finalizes his argument by writing,

Monochromatic radiation [light]... behaves in thermodynamic theoretical relationships as though it consisted of distinct independent energy quanta of magnitude $(R\beta/N)^{\sqrt{}}$... If then as far as the dependence of entropy on volume goes, monochromatic radiation (of sufficiently small density) behaves like a discontinuous medium consisting of energy quanta of magnitude $(R\beta/N)^{\sqrt{}}$.³⁶

[My Note: The relation $(R\beta/N)^{\sqrt{}}$ is equivalent to Planck’s $h^{\sqrt{}}$.]

These statements dramatically draw Einstein’s two rhetorical strategies together by redefining light according to Planck’s metaphor, ‘energy is discontinuous,’ and Boltzmann’s theories of particle-like ideal gases. This rhetorical move is decisive because Einstein shows that if one accepts the perspective created by Planck’s quantum metaphor, then one must also accept a new metaphor, “light is quantized.” This point is basically the core of Einstein’s argument.

The remainder of Einstein’s 1905 paper on light is devoted to three ‘observable’ applications of his light quanta metaphor to phenomena that resisted explanation by

³⁶ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 553.

Maxwell's classical theories. The most important of these three is the explanation of the photoelectric effect. As explained earlier in this chapter, the mystery surrounding the photoelectric effect was why frequency (color) and not intensity was related to the velocity of an electron emitted from a metal. Einstein's reinvention of light into quantum terms, however, described this phenomenon easily. He writes, "The simplest explanation is that a quantum transfers all its energy to a single electron."³⁷ In other words, Einstein reasoned that light strikes the metallic surface in particle-like energy "bundles" ($h\nu$), either knocking the electron out of the metal or reflecting harmlessly away. A light quanta of low frequency, therefore, would not have enough energy to knock out an electron and thus would bounce off the metal ($\epsilon = h\nu$). Einstein's explanation also showed why higher intensities of light kick out more electrons rather than electrons at higher and higher velocity. Higher intensity means more photons are kicking out individual electrons at specific quantum levels of velocity.

Employing his new metaphor 'light is quantized' to invent an explanation of the photoelectric effect, Einstein attempts to prove to his readers through 'observable' or empirical means that his new point of view is appropriate to the behavior of light in nature. For a scientist, Einstein's explanation of the photoelectric effect through the light quanta metaphor is surprisingly simple and seemingly plausible; yet it offers a description of the photoelectric effect that was unacceptable to Maxwell's theory of light. Indeed, because it violated Maxwell's theories, Planck and other scientists of his day thought Einstein had gone off in the wrong direction by arguing that light could be considered discontinuous. Kuhn claims that "for the entire period between their introduction in 1905 and the discovery of the Compton effect in 1922, very few theoretical physicists besides Einstein himself believed that light-particles provided a

³⁷ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 555.

basis for serious research.”³⁸ Ironically, throughout his life, Einstein considered the concept light quanta, or photons, to be one of his greatest scientific accomplishments.

Einstein’s New “Heuristic Point of View”

Einstein’s interpretation of Planck’s ‘energy is discontinuous’ metaphor more or less formed the basis of invention for his 1905 paper in which he reconceptualized light into discontinuous, or quantum, terms. Interpretation, as Davidson points out, is what gives meaning to metaphors. To summarize, Davidson states, “[A metaphor’s] interpretation reflects as much on the interpreter as on the originator... the act of interpretation is itself a work of the imagination.”³⁹ Indeed, Davidson suggests that “a metaphor makes us attend to some likeness, often a novel or surprising likeness, between two or more things.”⁴⁰ But, as he also claims, a metaphor does not contain some special meaning or insight that somehow transcends or gets ‘outside’ literal language. Rather, as Davidson notes, “the sentences in which metaphors occur are true or false in the normal, literal sense, for if the words in them don’t have special meanings, sentences don’t have special truth.”⁴¹ Essentially, therefore, the meaning of a metaphor is dependent on the interpretation of the listener or reader, not on an “interaction” or “ontological flash” that delivers special meaning or insight. Or, as Davidson states, “Generally, it is only when a sentence is taken to be false that we accept it as a metaphor and start to hunt out the hidden implications.”⁴² So, considering the importance of continuity to classical physics, the association of ‘energy’ with

³⁸ Kuhn, *Black Body Theory and the Quantum Discontinuity* 182.

³⁹ Davidson, “What Metaphors Mean” 29.

⁴⁰ Davidson, “What Metaphors Mean” 31.

⁴¹ Davidson, “What Metaphors Mean” 39.

⁴² Davidson, “What Metaphors Mean” 40.

'discontinuity' in Planck's 1900 quantum paper would more than likely have first struck Einstein as false in Davidson's sense. However, given the supportive role that the quantum metaphor played in Planck's black body argument, Einstein, as an interpreter of the text, might have been urged to work through the implications of the contrast the quantum metaphor created between energy and discontinuity. Seeing the value of the quantum metaphor, Einstein eventually embraced his interpretation of its meaning and thus came to view 'light,' an energy-related phenomenon, from a quite different perspective.

Much in this way, a scientific metaphor can go beyond its originator's intent or even understanding. As an interpreter of the quantum metaphor, Einstein was entitled to search out the "hidden implications" of the metaphor from his own rational account (*logos*) of reality. In essence, the act of interpreting the metaphor itself urged him to adopt a different point of view, or perspective, that warranted a reshaping of his previous beliefs to fit the point of view the quantum metaphor suggested. For Einstein, unlike Planck, the quantum metaphor implied a fundamental discontinuity in energy-related phenomena that went far beyond the domain of the black body problem. Indeed, Davidson seems to suggest that this crossing of domains is a common feature of metaphors. As Davidson notes,

But in fact there is no limit to what a metaphor calls to our attention, and much of what we are caused to notice is not propositional in character. When we try to say what a metaphor "means," we soon realize there is no end to what we want to mention.⁴³

And indeed, the 1905 light quanta paper illustrates that Einstein quite clearly interpreted the meaning of the quantum metaphor far more broadly than Planck would have

⁴³ Davidson, "What Metaphors Mean" 44.

accepted. Einstein turned from a passive acceptance of a classical description of 'energy as continuous' to a more unorthodox description in which energy was held to be discontinuous. In doing so, he opened the door to a fundamental rethinking of energy-related phenomena into concepts associated with discontinuity.

It is important, though, to recognize that the quantum metaphor by itself does not contain some discovered truth or fact that Planck stumbled across and Einstein happened to recognize. Rather, when Einstein came upon the metaphor, his interpretation urged him to more or less adopt a new point of view concerning energy that cohered with many of his other beliefs, especially atomism and statistical thermodynamics. Therefore, when he interpreted the metaphor, 'energy is discontinuous,' Einstein searched out its implications through other concepts that were already part of his rational account (*logos*) of reality. Specifically, as someone interested in atomism, thermodynamics, and empirical research, Einstein interpreted the metaphor by conceptualizing it into his broader understanding of discrete particles and empirical observations of the discontinuous nature of energy. Thus, for Einstein, the quantum metaphor became a guiding, or emergent, metaphor that invited to him rethink many of his previous beliefs about continuity in nature, especially concerning light. The act of interpreting the metaphor urged him to see things from a different perspective. Or, to put it another way, it 'turned' his rational account (*logos*) in such a way that he interpreted energy-related phenomena differently than he did before.

Indeed, the "emergent" metaphors 'energy is discontinuous' and 'light is quantized' formed the basis of invention for various parts of Einstein's light quanta argument. Whereas Planck had invented his argument from a perspective offered by the 'energy spectrum is an entropic phenomenon' metaphor, Einstein centered the 'energy is discontinuous' metaphor that was a parenthetical feature of Planck's argument in the 1900 quantum paper. Through his interpretation of this metaphor and the point of view

this interpretation offered, he could then invent a new description of light that was consistent with this ‘energy quanta’ metaphor. In other words, the two metaphors ‘energy is discontinuous’ and ‘light is quantized’ offered a consistent perspective, or “heuristic point of view” as Einstein called it, from which he could then invent a coherent argument for light quanta. Indeed, once he had shown that Planck’s constant could be viewed as “independent” of the black body theory, he could then proceed to use the implications of the quantum metaphor to reinterpret light into discontinuous or atomistic terms. Moreover, in the last part of the paper, he used the idea of ‘light quanta’ to invent a description of the photoelectric effect, illustrating how his ‘light is quantized’ metaphor allowed him to offer a description of the light phenomenon that succeeded where continuous, or wave, theories of light seemed to fail.

Interestingly, though, Einstein did not seek to disprove the continuous description in the 1905 light quanta paper. Instead, he merely suggested that experimental observations of energy and light often led to contradictions with Maxwell’s wave theories. But, to Einstein, the potentially flawed or incomplete status of Maxwell’s theories probably in some measure justified an attempt to explain light from a new point of view. Once he had embraced a new “quantum” perspective, the quantum metaphor itself formed the basis for what could be held to be rational, logical, or true. As such, the ‘logic’ of the quantum metaphor removed the ambiguities from explaining light in discontinuous terms. Nevertheless—and I think this is a crucial point—Einstein did not attempt to discredit or reconcile wave theory of light with his own quantum theory of light. In fact, he wrote rather clearly that “the wave theory... has proved to be correct in representing purely optical phenomena and will probably not be replaced by any other theory.”⁴⁴ At first, this quote is puzzling, because it seems to

⁴⁴ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 544.

suggest that light is a wave in some situations and a particle in other situations. No doubt, this inconsistency was one of the reasons Einstein's theory was dismissed by people like Planck. Einstein, however, seemed to believe that he was offering a new "heuristic point of view" for light and not a comprehensive theory. Later, in 1909, he was to return to his light quanta hypothesis and try to reconcile the wave and particle descriptions of light. We will discuss this attempt in a moment.

If my understanding of Einstein's interpretation and usage of the quantum metaphor is correct, then his invention strategy for the 1905 light quanta argument becomes rather clear. The inability of Maxwell's wave theory of light to completely explain light suggested to Einstein that theories based on the assumption that energy and light are continuous were flawed or incomplete. Reflecting this conclusion, Einstein stated in his introduction, "the theory of light that operates with continuous spatial functions may lead to contradictions with observation if we apply it to the phenomena of the generation and transformation of light."⁴⁵ Since for the young Einstein, the real priority was to explain phenomena empirically, he was willing to skeptically question theories if such a challenge might lead to a more accurate account of a phenomenon. For this reason, like Planck, he was willing to employ concepts from thermodynamics, like atomism and entropy, to explain the behavior of light even though the connection between electromagnetism and thermodynamics was not obvious. To head off his readers' doubts about his application of the quantum metaphor, however, Einstein argued for the independent status of Planck's constant h .⁴⁶ In doing so, he created rhetorically an either/or choice for his audience

⁴⁵ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 544-545.

⁴⁶ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 547.

between the notion of an elementary quanta and a seemingly flawed or incomplete wave theory of light. So when, later in the paper, Einstein offered plausible descriptions of three different light-related phenomena using his concept of light quanta, it probably seemed as though his results justified his unorthodox conclusions even though they challenged the completeness of Maxwell's theories.

Conflicting Dominant Metaphors

The discussion brings me to an issue on which I will conclude. If Einstein's light quanta hypothesis is held to be an obvious truth by today's scientists, why did the physicists of Einstein's day reject it for almost two decades? Interestingly, acceptance of the quantum postulate ($\epsilon=h\nu$) alone was not a direct prerequisite for acceptance of the concept of light quanta. Otherwise, the Einstein's theory of light quanta would have been embraced somewhere around 1913 when the quantum theory took center stage in the scientific community. However, until 1922, as Kuhn points out, Einstein was one of very few scientists who believed in light quanta.

One could point to a few historical factors that might have impeded acceptance of Einstein's argument—like World War I or the fact that Einstein was an unknown patent clerk in Bern until 1908—but I believe much of our answer can be found in Einstein's 1905 light quanta paper itself. In the introduction, Einstein suggests that the wave theory of light will never be replaced.⁴⁷ And yet, the remainder of his paper treats light as essentially discontinuous and particle-like, not explaining how the wave-like features of light fit into his new "heuristic point of view" concerning light. Indeed, by the end of the paper, it seems as though Einstein is pursuing a particle or quantum theory of electromagnetism in which the wave-like behavior of light is presumed to fit into a broader corpuscular interpretation. I imagine most physicists would have found

⁴⁷ Einstein, "Concerning a Heuristic Point of View about the Creation and Transformation of Light" 544.

his argument for light quanta difficult to accept because his evidence for a corpuscular theory was not well-established.⁴⁸ First, his use of the quantum metaphor would have been questionable to his readers. To many physicists, it was at best a minor ad hoc constant that filled a gap in Planck's formula for the energy spectrum.⁴⁹ Second, in spite of the success of his light quanta hypothesis toward explaining the photoelectric effect and two other scientific anomalies, the overwhelming body of empirical evidence favored Maxwell's wave theories. Indeed, even the measurements of the photoelectric effect were rather imprecise, leaving the question open as to whether Maxwell's theories eventually would explain it.⁵⁰

Most importantly, though, in this 1905 light quanta paper, Einstein knowingly or unknowingly discerns a future aspect of *quantum mechanics* that would change physics completely—the wave-particle duality of light. In 1909, Einstein returned to his studies on light and argued that electromagnetic radiation exhibits both wave-like and particle-like behavior. He reported,

I already attempted earlier to show that our current foundations of the radiation formula have to be abandoned... It is my opinion that the next phase in the development of theoretical physics will bring us a theory of light that can be interpreted as a kind of fusion of the wave and the [particle] theory... [The] wave structure and [the] quantum structure... are not to be considered mutually incompatible.⁵¹

⁴⁸ Kuhn, *Black Body Theory and the Quantum Discontinuity* 195, 200, 222.

⁴⁹ Kuhn, *Black Body Theory and the Quantum Discontinuity* 189.

⁵⁰ Bernstein, *Einstein* 200.

⁵¹ Quoted in Pais, *Niels Bohr's Times* 231.

Einstein believed in 1909 that at some point the wave and particle theories of light would be reconciled into one theory.⁵² At the time, though, he did not realize the full significance of this duality. It was in 1923, when Louis de Broglie published his argument for the wave properties of *matter* that the importance of the wave-particle duality was more fully understood. In many ways, de Broglie's explanation of matter through Einstein's understanding of the of wave-particle duality of light led to the development of quantum mechanics.

Indeed, the problem with Einstein's 1905 light quanta paper is that it seems to support two fundamentally different interpretations of light based on two seemingly contradictory dominant metaphors in physics. The first metaphor, 'light is a wave,' urges one to view light as essentially continuous. The second metaphor, 'light is quanta,' on the other hand, urges a discontinuous (particle) interpretation of light. For the most part, these two interpretations of the light phenomenon are completely at odds with each other and seem to contradict. Few physicists would have given up the highly successful perspective offered by the 'light is a wave' metaphor for 'light is quanta' based on Einstein's rather questionable argument. Nevertheless, it is important to note that Einstein's 1905 light quanta paper for the first time brings continuous (wave) and discontinuous (particle) interpretations of reality into direct contrast. In doing so, Einstein set two competing dominant metaphors from classical physics into direct conflict. According to classical physics, one of these two metaphors would eventually overcome the other. But, as Niels Bohr pointed out in 1927 in the Copenhagen interpretation of quantum mechanics, both perspectives of reality are necessary to gain a comprehensive view of the behavior of matter and light. I will analyze Bohr's argument in the next chapter.

⁵² Hund, *The History of Quantum Theory* 49.

CHAPTER FIVE
NIELS BOHR AND THE COPENHAGEN INTERPRETATION:
NEW METAPHORS FOR A QUANTUM REALITY

This violent reaction on the recent development of modern physics can only be understood when one realizes that here the foundations of physics have started moving; and that this motion has caused the feeling that the ground would be cut from science. At the same time, it probably means that one has not yet found the correct language with which to speak about the new situation.

Werner Heisenberg

If one wanted to identify to a specific time when a new scientific metaphor became a prominent feature of the body of scientific beliefs, the introduction of the ‘quantum theory of the atom’ in 1913 would be a solid candidate. In 1913, a young Danish physicist, Niels Bohr, introduced many members of the scientific community to the ‘energy is quantized’ metaphor by offering a nuclear description of the atom that employed quantum relations.¹ The ‘Bohr atom’ itself was quite simple. It proposed that electrons orbit in discrete stationary states around the nucleus of an atom. Electrons then jump closer or further away from the nucleus in discrete ‘quantum jumps’ from orbit to orbit. Each jump, Bohr argued, would then be accompanied by the emission or absorption of radiation in the form of a quantum unit of energy, $h\nu$. Bohr’s atom became the centerpiece of what is now often called the “old” quantum theory, and it convinced many physicists that Planck’s ‘energy is discontinuous,’ once considered an ad hoc assertion, provided a promising perspective from which to invent new theories of atomic phenomena. By the early 1920s, however, Bohr’s quantum theory of the atom, which Einstein called the “highest form of musicality in the sphere of thought,” seemed to be reaching the limits of its ability to account for atomic phenomena.²

¹ Niels Bohr, “On the Constitution of Atoms and Molecules,” *Philosophical Magazine* 26 (1913): 1-19.

² Einstein, “Autobiographical Notes” 45.

Historian Abraham Pais writes, "It had become increasingly obvious that all was far from well in physics... the Bohr-Sommerfeld quantum rules appeared quite often to be highly successful, yet, in a deep sense, they were paradoxical, as Bohr well knew."³

It was an older Bohr in 1927 who set out to explain these paradoxes in the form of the "Copenhagen interpretation" of the quantum theory. With the Copenhagen interpretation, Bohr and a group of physicists that included Werner Heisenberg, Wolfgang Pauli, and Max Born offered the first comprehensive account of the quantum theory that finally broke ties with classical physics. In this chapter, I will analyze Bohr's 1927 speech, "The Quantum Postulate and the Recent Development of Atomic Theory,"⁴ in which he introduced the Copenhagen interpretation. Using metaphorical analysis, I will illustrate how Bohr introduced the metaphors 'reality is complementary' and 'physics is uncertain' into physics and used them to couple two dominant metaphors from classical physics (i.e. wave and particle interpretations) into a dramatically new interpretation of reality.⁵ Also, I will show how Bohr used the new perspective offered by the 'complementarity' and 'uncertainty' metaphors to challenge fundamental tenets of classical physics like causality, objectivity, and certainty. Finally, I will illustrate how he offered these new metaphors as the basis of invention for descriptions and theories in quantum mechanics.

Rhetorical Situation

In the spring of 1926, the physics community faced a dilemma. Two profoundly different theories of quantum physics had emerged that offered seemingly

³ Pais, *Neils Bohr's Times* 269.

⁴ Reprinted in Niels Bohr, *Atomic Theory and the Description of Nature* (Cambridge: Cambridge UP, 1934) 52-91. Also, a recent reprint of this book of the same title is offered by the Oxbow Press (Woodbridge, Conn.: Ox Bow, 1987).

⁵ Historian Friedrich Hund refers to the Copenhagen interpretation as the "completion of quantum mechanics." See Hund, *The History of Quantum Theory* 154.

contradictory interpretations of reality. The first, *matrix mechanics*, was introduced in the summer of 1925 by Heisenberg. Stressing a particle-based understanding of matter, matrix mechanics preserved implicitly the metaphor 'energy is discontinuous' that had become an accepted part of quantum theory since Bohr's 1913 quantum theory of the atom. Indeed, by 1925, many other phenomena had been reinterpreted into "quantum" terms, so one might even say that the broader metaphor 'nature is discontinuous' better represented the quantum metaphor. The second theory, *wave mechanics*, was introduced by Erwin Schrodinger in the spring of 1926. To physicists' surprise, it appeared to reclaim the concept of *continuity* from classical physics by asserting that matter is completely made up of bundles of "matter waves." The fundamental differences between these two theories were evident in their mathematics. Matrix mechanics relied on an algebraic approach that emphasized quantum discreteness. Wave mechanics, on the other hand, used differential calculus to develop continuous wave functions, thereby stressing continuity.⁶ Thus, the greatly different mathematics on which both theories were based seemed to lead to two irreconcilable perspectives from which to interpret reality. Further complicating the dilemma, in the summer of 1926 Schrodinger showed that his wave mechanics and Heisenberg's matrix mechanics offered essentially identical results despite their fundamental conceptual differences.

Though matrix mechanics offered highly accurate descriptions of phenomena at the atomic level, Schrodinger's wave mechanics was gratefully welcomed by the physics community. Wave mechanics avoided the tedious matrix algebra of Heisenberg's theories by employing more familiar methods that used differential equations.⁷ Indeed, many physicists thought Schrodinger's theory of wave mechanics

⁶ Max Jammer, *The Conceptual Development of Quantum Mechanics* (New York: McGraw-Hill, 1966) 271-272.

⁷ Pais, *Niels Bohr's Times* 43.

was a form of a deliverance because they could then avoid learning the complicated matrix mathematics.⁸ More important, though, for many physicists, wave mechanics strongly indicated that the quantum theory's reliance on discontinuity might eventually prove to be wrong. Historian Max Jammer writes "Those who in their yearning for continuity hated to renounce the classical maxim *natura non facit saltus* acclaimed Schrodinger as the herald of a new dawn."⁹ Einstein, who had grown less satisfied with the notion of discontinuity in any absolute sense, wrote to Schrodinger on April 26, 1926, "I am convinced that you have made a decisive advance with your formulation of the quantum condition, just as I am equally convinced that the Heisenberg-Born route is off the track."¹⁰

Thus, the physics community found itself at an impasse, because matrix and wave mechanics suggested profoundly different ways of describing quantum reality that nevertheless led to the same results. Matrix mechanics implied that reality was essentially discontinuous, continuing in the tradition of the "old" quantum theory. Stressing this discontinuous nature of phenomena, Heisenberg's arguments for matrix mechanics showed that one could describe particles, specifically electrons, in terms of matrices of momentum and position. The rows and columns of the matrices were believed to actually correspond to the discrete energy states in which particles would be found.¹¹ Schrodinger's arguments for wave mechanics, however, suggested that waves are the substance of matter, and that particles are merely stable aggregates of waves. In

⁸ Pais, *Niels Bohr's Times* 43.

⁹ Jammer, *The Conceptual Development of Quantum Mechanics* 271.

¹⁰ Einstein to Schrodinger, 26 April 1926. Reprinted in K. Przibram, ed., *Letters on Wave Mechanics* (New York: Philosophical Library, 1967)

¹¹ Hund, *The History of Quantum Theory* 278. The mathematics are not important to this argument. For an indepth discussion of matrix mechanics and wave mechanics, several sources, including Hund, are available.

other words, wave mechanics assumed that particles, such as electrons, are made up of linear harmonic oscillator wavefunctions.¹² Schrodinger wrote, “Our wave packet holds *permanently together*, does *not* expand over an ever greater domain in the course of time.”¹³ Moreover, Schrodinger believed that the wave nature of matter in his theories would eventually expose quantum theory to be a new development in the tradition of classical physics. If so, he argued, the discontinuity observed by in atomic phenomena would be due to a finite number of discrete nodes in the matter waves, similar to the nodes in a vibrating string.¹⁴

By late 1926, the advocates of matrix mechanics and wave mechanics had both set about attempting either to prove the other side wrong or to reconcile the other theory into their own. The major figures of the scientific community divided into two rather clear factions. Heisenberg, Pauli, Born, and Paul Dirac became the advocates for matrix mechanic’s discontinuous description of reality. Schrodinger, Einstein, Planck, and de Broglie argued for the continuous description supported by wave mechanics. Conspicuously undecided, Bohr offered numerous criticisms of Heisenberg’s matrix mechanics, but also did not accept Schrodinger’s continuum assertions either. At some points, the debate grew somewhat bad-tempered with Schrodinger stating publicly in response to Heisenberg’s theory “I was discouraged if not repelled.” Heisenberg, responding to Schrodinger’s theory, wrote to Pauli, “The more I ponder about the physical part of Schrodinger’s theory, the more disgusting it appears to me.”¹⁵

¹² Pais, *Niels Bohr’s Times* 285.

¹³ Quoted in Pais, *Niels Bohr’s Times* 285.

¹⁴ Erwin Schrodinger, *Four Lectures on Wave Mechanics* (London: Blackie, 1928) 9-13.

¹⁵ Quoted in Jammer, *The Conceptual Development of Quantum Mechanics* 271-272.

Despite the bad feelings between both factions, however, by the summer of 1926, it seemed as though an answer were possible. The most significant attempt to reconcile matrix mechanics and wave mechanics was made by Born. Though an advocate of quantum discontinuity, he began publishing papers on wave mechanics in which he argued that the waves in Schrodinger's theories were actually "probability waves" rather than matter waves. Born claimed that one could only find the position of a discontinuous particle by using Schrodinger's wave formulas to calculate the *probability* that it would appear in a specific place in a wave function. Historian Pais suggests that Born developed his concept of probability waves after reading an unpublished work in which Einstein claimed that light quanta move in a 'ghost field' that determines the probability that it will follow a particular path.¹⁶ Seeming to confirm Pais' suggestion, Born stated in his Nobel speech,

Again an idea of Einstein's gave me the lead. He had tried to make the duality of particles—light quanta or photons—and waves comprehensible by interpreting the square of the optical wave amplitudes as probability density of the occurrence of photons. This concept could at once be carried over to the [Schrodinger] ψ -function: $|\psi|^2$ ought to represent the probability density for electrons (or other particles).¹⁷

Essentially, then, Born showed that Schrodinger's equation still could lead to a discontinuous, particle-based interpretation of nature. However, in order for his 'probability wave' theory to work, Born realized that he needed to reinterpret other aspects of physics. His arguments for probability waves, he claimed, also challenged classical notions of *causality* and *determinism*. He argued that

¹⁶ Pais, *Niels Bohr's Times* 287.

¹⁷ Max Born, *Nobel Lecture--Physics: 1942-1962* (Amsterdam: Elsevier, 1964) 266.

In the first place it is clear that the dualism, wave-corpuscle, and the indeterminateness essentially involved therein, compel us to abandon any attempt to set up a *deterministic theory*. The *law of causality*, according to which the course of events in an isolated system is completely determined by the state of the system at time $t = 0$, loses its validity, at any rate in the sense of classical physics.¹⁸

Supporters of wave mechanics like Einstein, Schrodinger, and Planck adamantly rejected the indeterminism and acausality of Born's theory. In a December 4, 1926 letter to Born concerning probabilistic wave mechanics, Einstein wrote rather guardedly:

Quantum mechanics is certainly imposing. But an inner voice tells me that it is not yet the real thing. The theory says a lot, but does not really bring us closer to the secrets of the 'old one.' I, at any rate, am convinced that *He* is not playing at dice.¹⁹

Later, Einstein became the most ardent and formidable critic of theories that adopted views in which probability played an important role, especially the Copenhagen interpretation. Schrodinger and Planck also never accepted the abandonment by quantum mechanics of determinism and causality.

Originally, Bohr kept his distance from the debate between matrix and wave mechanics, working mainly through his protégés, like Heisenberg, Pauli, and Dirac, at the Copenhagen Institute. By the winter of 1926, however, he and the other members of the Copenhagen school began working toward a new comprehensive theory of

¹⁸ Max Born, "Wave Corpuscles," eds., H. Boorse, and L. Motz (New York: Basic Books, 1966): 1093.

¹⁹ This rather famous statement appears in a December 4, 1926 letter to Born reprinted in Max Born, *The Born-Einstein Letters* (New York: Macmillan, 1971).

quantum mechanics. Several challenges faced Bohr and the members of his institute at Copenhagen. First, they needed to resolve the notion of ‘indeterminacy’ in Born’s theory of probability waves. Indeed, Born’s arguments for statistical interpretations of wave mechanics became a central feature of the Copenhagen Institute’s understanding of quantum mechanics.²⁰ Another challenge was the growing sense that somehow both matrix and wave mechanics offered equivalent but wholly independent ways to talk about reality. Physicists observed that electrons—the common object of study at this time—could behave as waves *and* particles; however, electrons did not exhibit both wave and particle properties at the same time. Indeed, physicists found it troubling that the wave and particle properties electrons exhibited seemed to depend primarily on how physicists *chose* to observe them. Electrons could exhibit the diffraction pattern commonly associated with particles *or* the interference pattern typically associated with wave. However, electrons could not exhibit both diffraction and interference patterns simultaneously. Paradoxically, electrons seemed to show the same irreconcilable particle-wave duality that Einstein had ascribed to light in 1905 and later in 1909.

Bohr’s 1927 Copenhagen Interpretation Lecture

Holton writes that Bohr’s 1927 Copenhagen Interpretation lecture “marked a turning point in the road from which our view of the intellectual landscape, in science and other fields, will forever be qualitatively different from that of earlier periods.”²¹ Indeed, it is hard to overstate the importance of this lecture to the development of quantum mechanics and modern physics in general. In essence, it introduced what Bohr called “a general point of view” from which physicists could interpret natural phenomena in way that was dramatically different than that offered by classical

²⁰ Pais, *Niels Bohr’s Times* 288-289.

²¹ Holton, *Thematic Origins of Scientific Thought* 99.

physics.²² As a result, Bohr's Copenhagen Interpretation lecture initiated a large-scale change in the way physicists conceptualize reality.

The organization of Bohr's lecture can be broken down into three main parts that I will use to structure my analysis. In the first part, Bohr begins with a short introduction in which he states his purpose in broad terms. In the second part, he uses the quantum metaphor, 'nature is discontinuous,' to invent and introduce the concept of 'complementarity,' a central feature of the Copenhagen interpretation of quantum mechanics. In this part of his argument, he also uses the quantum metaphor to argue that the "point of view" created by the quantum theory and complementarity implicitly undermines classical physics' reliance on 'causality,' 'objectivity,' and 'certainty.' And in the final part, Bohr employs the concept of complementarity to invent explanations of several important paradoxes facing quantum mechanics. In this last part, he also introduces a new interpretation of 'uncertainty' in physics and then uses it to redefine the nature of inquiry in physics, namely measurement and prediction, into terms that are appropriate to a "complementary" theory of reality. In this analysis of Bohr's lecture, I will specifically concentrate on how Bohr introduces complementarity as a new dominant metaphor for quantum mechanics and then uses this metaphor as the basis of invention for the rest of his argument in which he describes reality and the discipline of physics from a radical new perspective.

Introduction

The introduction of the lecture conceals its important purpose. Bohr explains that he had been asked to offer "an account of the present state of the quantum theory."²³ Alluding to a "remarkable recent development," he hints that his original purpose has changed when he suggests that

²² Bohr, *Atomic Theory and The Description of Nature* 52.

²³ Bohr, *Atomic Theory and The Description of Nature* 53.

I shall try, by making use only of simple considerations, and without going into any details, of technical mathematical character, to describe to you a certain general point of view... which I hope will be helpful in order to harmonize the apparently conflicting views taken from different scientists.²⁴

This disarming remark understates the formidable purpose that Bohr had set out for himself. However, he hints at the significance of his “general point of view” when he states at the end of the introduction, “We have perhaps more occasion than ever at every step to be remindful of the work of the old masters who have prepared the ground and furnished us with our tools.”²⁵

Nature is Complementary

The body of Bohr’s paper begins by calling attention to a fundamental difference between the quantum theory and descriptions of reality developed by classical physics. Bohr writes, “The quantum theory is characterized by the acknowledgment of a fundamental limitation in the classical physical ideas when applied to atomic phenomena.”²⁶ Bohr explains that the differences between the quantum theory and classical theories of physics are brought about because the quantum postulate at the core of quantum descriptions of reality violates the basic ideals of classical physics. Reinforcing this point, he states that the quantum theory’s essence may be expressed in the so-called quantum postulate, which attributes to any atomic process an essential discontinuity, or rather individuality, completely foreign to the classical theories and symbolized by Planck’s quantum of action.²⁷

²⁴ Bohr, *Atomic Theory and The Description of Nature* 52.

²⁵ Bohr, *Atomic Theory and The Description of Nature* 53.

²⁶ Bohr, *Atomic Theory and The Description of Nature* 53.

²⁷ Bohr, *Atomic Theory and The Description of Nature* 53.

In making this statement, Bohr reiterates the dominant ‘quantum’ metaphor that had served as the basis for the invention of arguments in the “old” quantum theory from 1905 to 1926. It is noteworthy, though, that only two decades after the novel usage of the quantum metaphor in Einstein’s 1905 paper, Bohr employs the quantum metaphor with absolute confidence as though it were a matter of common knowledge. Indeed, for Bohr and a great majority of his audience, the quantum metaphor, had become a dominant metaphor in their rational accounts (*logoi*) of phenomena at the atomic level. As a dominant metaphor, therefore, the quantum metaphor offered a more or less similar perspective from which Bohr and his audience interpreted, talked about, and conceptualized reality at the atomic level. By reiterating the metaphor itself, he seems to stress that the point of view it offers has led to success in spite of its violation of the classical theories.

Despite the success of the quantum theory, though, Bohr goes on to claim that the introduction of the quantum postulate has created a problematic “situation... of a peculiar nature, since our interpretation of the experimental material rests essentially on classical concepts.”²⁸ In other words, Bohr seems to suggest that the current lack of “harmony” in physics has developed because the point of view urged by the quantum theory seems to conflict with concepts retained from classical physics that were being used to describe the behavior of natural phenomena. Essentially, Bohr points out to his audience that the physics community has been interpreting and explaining phenomena from two very different “points of view” or perspectives that are in conflict with each other. The first perspective, urged by the quantum metaphor, ‘nature is discontinuous,’ suggests that reality is essentially quantized, thus violating the notion of a continuum in classical physics. However, as Bohr points out, the second perspective—that of

²⁸ Bohr, *Atomic Theory and The Description of Nature* 53.

classical physics and the continuum—had become so ingrained in the concepts physicists use to describe phenomena that theories and descriptions invented through the quantum metaphor seem to contain “peculiarities.”

In making this distinction between the “classical” and “quantum” points of view, Bohr suggests that there is a fundamental difference between classical and quantum interpretations of reality that must be resolved. Bohr, then, identifies what he believes is the conflict’s source, and he offers a solution. He states,

[The quantum postulate] implies a renunciation as regards the causal time-space co-ordination of atomic processes. Indeed, our usual description of physical phenomena is based entirely on the idea that the phenomena concerned may be observed without disturbing them appreciably.²⁹

In other words, Bohr claims that the quantum postulate urges a renunciation of the traditional notion of “causality” in physics. In making this claim, Bohr identifies for his audience the essential distinction between the quantum and classical “points of view.” Classical physics relies on the notion that “changes in state” at the atomic level behave in a strictly *causal* way; whereas, in quantum physics, causality, at least in the classical sense, is not a required feature of atomic description.³⁰ Bohr points out, however, that the “usual” descriptions of phenomena rely on the presumption of causality to develop so-called “objective” and “certain” accounts of reality in which the experimenter is assumed to be completely separate from the observed phenomenon.

²⁹ Bohr, *Atomic Theory and The Description of Nature* 53.

³⁰ Bohr’s discussion of causality in this essay is rather unfinished. Causality, however, was a central feature of his later debates with Einstein. Also, causality has been heavily debated by philosophers. See Aage Petersen, *Quantum Physics and the Philosophical Tradition* (Cambridge: MIT P, 1968) 107-109 and Milic Capek, *The Philosophical Impact of Contemporary Physics* (New York: Van Nostrand-Reinhold, 1961) 289-329, 337-341.

In essence, Bohr illustrates that the differing perspectives of the quantum theory and classical physics are based on two different dominant metaphors that are essentially incompatible: quantum theory relies on the dominant metaphor 'nature is discontinuous' while classical physics relies on the dominant metaphor 'nature is causal.' Recognizing that the perspectives offered by these two metaphors are incompatible, Bohr claims that acceptance of the perspective urged by the quantum metaphor implies that one should then renounce the classical perspective in which 'causal' interpretations of phenomena are overwhelmingly dominant. Interestingly, though, Bohr does not challenge the concept of causality in classical physics by arguing against it directly. Rather, he attempts to show that its renunciation is a rational implication of the quantum postulate itself. He states,

Now, the quantum postulate implies that any observation of atomic phenomena will involve an interaction with the agency of observation not to be neglected.

Accordingly an independent reality in the ordinary physical sense can neither be ascribed to the phenomena nor to the agencies of observation.³¹

Furthermore, he states, "If in order to make observation possible we permit certain interactions with suitable agencies of measurement, not belonging to the system, an unambiguous definition of the state of the system is no longer possible."³² In making these claims, Bohr suggests that the quantum postulate implies that two fundamental ideals of physics, "independent observation" (objectivity) and "unambiguous definition" (certainty), are ultimately unfounded. If so, Bohr claims, "there can be no question of causality in the normal sense of the word."³³ Therefore, Bohr's challenges

³¹ Bohr, *Atomic Theory and The Description of Nature* 54.

³² Bohr, *Atomic Theory and The Description of Nature* 54.

³³ Bohr, *Atomic Theory and The Description of Nature* 54.

the notion of causality in physics by suggesting that two of its most important implications, objectivity and certainty, are untenable. Moreover, he seems to be suggesting at this point in the lecture that if one can show that objectivity and certainty are unfounded, then the classical notion of causality too is impossible to defend.

Needless to say, Bohr's argument early in the body of his lecture is extremely complex, but I believe his claims become more accessible when viewed metaphorically. Bohr exposes two tenets of classical physics, 'objectivity' and 'certainty,' to be essentially metaphors that urge physicists to develop 'causal' descriptions of reality. As dominant metaphors of classical physics, objectivity ('physics is objective') and certainty ('physics is certain') urge physicists to conceive of their relationship to phenomena from a particular point of view in which causality is a dominant feature of any description of nature. Bohr suggests that the "point of view" offered by the quantum metaphor invalidates these two metaphors, 'physics is objective' and 'physics is certain,' and thus also challenges the 'nature is causal' metaphor that forms the basis of classical interpretations of reality. To support his assertions, Bohr points out that the quantum metaphor implies, as stated above, that "any observation of atomic phenomena will involve an interaction with the agency of observation not to be neglected;" thus the quantum metaphor discredits any attempt to interpret phenomena from an "objective point of view."³⁴ Also, because these interactions will always disturb the phenomenon being observed, the quantum metaphor implies that "an unambiguous definition of the state of the system is no longer possible," denying physics will ever be "certain."³⁵ Therefore, he suggests that the inability of physicists to be 'objective' or 'certain' in the classical sense implies a renunciation of the causal understanding of reality itself. In

³⁴ Bohr, *Atomic Theory and The Description of Nature* 54.

³⁵ Bohr, *Atomic Theory and The Description of Nature* 54.

other words, he argues that *how* one interprets the behavior of ‘natural phenomena’ is dramatically changed by the acceptance of the quantum metaphor. From the perspective urged by the quantum metaphor, natural phenomena cannot be properly interpreted as causal, and physicists, as agents, must be inevitably understood to be a part of the phenomenon they are studying.

Having renounced classical understandings of causality, objectivity, and certainty as untenable in the quantum theory, Bohr then turns to the solution that he believes will quiet the disharmony in physics. He states,

The very nature of the quantum theory thus forces us to regard the space-time co-ordination [meaning: particle behavior] and the claim of causality [meaning: wave behavior], the union of which characterizes the classical theories, as complementary but exclusive features of the description. . . Indeed, in the description of atomic phenomena, the quantum postulate presents us with the task of developing a “complementarity” theory.³⁶

Interestingly, Bohr does not suggest that the quantum metaphor, ‘nature is discontinuous,’ should replace the dominant metaphor of classical physics ‘nature is causal.’ Rather, he introduces a new dominant metaphor for quantum mechanics that he claims is brought about by the nature of the quantum theory itself. In the passage above, the metaphor Bohr introduces to serve as the basis of quantum mechanics is ‘nature is complementary.’ Put concisely, the concept of “complementarity” in quantum mechanics suggests that if physicists observe one feature of a phenomena (e.g. its particle-like properties) another feature will be excluded from being observed (e.g. its wave-like properties). However, both of these ‘complementary’ accounts are necessary

³⁶ Bohr, *Atomic Theory and The Description of Nature* 55. The bracketed text in this quote is taken from Pais’ *Niels Bohr’s Times* 315. I believe it is helpful toward understanding what Bohr is comparing.

to develop the broader explanation of a particular phenomenon. For the most part, Bohr argues that interpreting nature in ‘complementary’ terms urges physicists to dramatically change the way they describe phenomena, because it suggests that reality is essentially *pluralistic*. By introducing the notion of complementarity into physics, Bohr suggests that in quantum mechanics, unlike in classical physics, a clear description of a phenomenon does not rely on, as Holton writes, “simplification and reduction to a single, directly comprehensible model, but an exhaustive overlay of different descriptions that incorporate apparently contradictory notions.”³⁷ The implications of the ‘nature is complementary’ metaphor, therefore, suggest that the wholeness of nature can only be characterized through antithetical points of view. Also, complementarity denies that one absolutely true description is possible; instead, physicists need to invent theories in which complementary points of view are used describe a particular phenomenon.³⁸

Essentially, by developing the concept of complementarity, Bohr broadly interprets and then generalizes the wave-particle dualistic nature of phenomena that Einstein first illustrated in the behavior of light in his 1905 and 1909 papers on light quanta. Unlike Einstein, though, Bohr suggests that the wave-particle dualism itself is a aspect of nature that physicists need to embrace. He states, “The two views of the nature of light are rather to be considered as different attempts at an interpretation of experimental evidence in which the limits of the classical concepts is expressed in complementary ways.”³⁹ Likewise, Bohr argues, matter is subject to complementarity. He notes,

³⁷ Holton, *Thematic Origins of Scientific Thought* 102.

³⁸ Nobel physicist Steven Weinberg takes up the ‘final theory’ cause in his book, *Dreams of a Final Theory*. He argues that certainty may not be attainable, but scientists can still develop a final theory of physics that is absolutely true. See Weinberg, *Dreams of a Final Theory*.

³⁹ Bohr, *Atomic Theory and The Description of Nature* 56.

we have consequently in the question of the nature of matter... to face an inevitable dilemma which has to be regarded as the very expression of experimental evidence. In fact, here again we are not dealing with contradictory but with complementary pictures of phenomena.⁴⁰

Indeed, for Bohr, 'nature is complementary' becomes the dominant metaphor of quantum mechanics, urging physicists to interpret and conceptualize reality in a pluralistic way that is very different than classical physics. Moreover, the complementarity metaphor serves as the basis of the "generalized point of view" that Bohr mentioned in the introduction to the lecture.

Later in his lecture, Bohr uses the complementarity metaphor to invent a comprehensive interpretation of quantum mechanics in which matrix mechanics and wave mechanics are understood to be complementary to one another. Bohr writes the two formulations of the interaction problem might be said to be complementary in the same sense as the wave and particle idea in the description of the free individuals. The apparent contrast in the utilization of the energy concept in the two theories is just connected with this difference in the starting-point.⁴¹

Indeed, this coupling of matrix mechanics and wave mechanics into a "complementary" theory of quantum mechanics is the most important conclusion of the 1927 Copenhagen Interpretation lecture. In making this claim, Bohr argues that the wave-particle duality of phenomena is a prevailing feature of reality that resists any attempts to reconcile one interpretation of a particular phenomena into the other.⁴²

⁴⁰ Bohr, *Atomic Theory and The Description of Nature* 56.

⁴¹ Bohr, *Atomic Theory and The Description of Nature* 76.

⁴² Holton, *Thematic Origins of Scientific Thought* 117.

Physics is Uncertain

In the remainder of the 1927 Copenhagen Interpretation lecture, Bohr explores the implications of the complementarity metaphor for his audience and illustrates the “generalized point of view” the metaphor offers. One of the most striking implications, Bohr points out, is that if ‘nature is complementary’ then the study of physics will ultimately be always “uncertain.” Thus, he argues, physics will need to rely on statistical interpretations that always calculate “probabilities” or “possibilities,” not certainties. He explains this point in the following passage:

It must not be forgotten, however, that in classical theories any succeeding observation permits a prediction of future events with ever-increasing accuracy, because it improves our knowledge of the initial state of the system. According to the quantum theory, just the impossibility of neglecting the interaction with the agency of measurement means that every new observation introduces a new uncontrollable element... it must be realized that we are dealing with an abstraction, from which not unambiguous information concerning the previous or future behavior of the individual can be obtained.⁴³

The “uncontrollable element” Bohr identifies is brought about by the fundamental role that complementarity plays in quantum mechanics. Whereas the dominant metaphor ‘nature is causal’ from classical physics urges one to assume that physics is ideally ‘objective’ or ‘certain,’ the dominant metaphor ‘nature is complementary’ of quantum mechanics urges one to assume that physics is inevitably ‘uncertain’ and thus reliant on statistical descriptions of reality.

As such, Bohr argues, an unambiguous description of reality is impossible to attain in quantum mechanics. Bohr argues that the ‘uncertain’ nature of quantum

⁴³ Bohr, *Atomic Theory and The Description of Nature* 67-68.

mechanics is brought out “most strikingly” in the “uncertainty relations” that had been developed by Heisenberg earlier in 1927. To illustrate, Bohr starts out by deriving Heisenberg’s formulaic representation of the uncertainty relation:⁴⁴

$$\Delta p \Delta q \geq h \text{ and } \Delta E \Delta t \geq h$$

Δp is the uncertainty of knowing position
 Δq is the uncertainty of knowing momentum
 ΔE is the uncertainty of knowing the energy
 Δt is the uncertainty of knowing the time duration
 h is Planck’s constant

Bohr points out that these formulas essentially set a limit on physicists’ abilities to measure a particular phenomenon, because they establish what physicists can and cannot observe.⁴⁵ The formulas prescribe that if one knows the exact position of a particle (uncertainty (Δq) = 0), then the uncertainty of knowing the momentum of the particle goes to infinity ($\Delta p = \infty$) and vice versa. In other words, the closer physicists come to measuring the position of an object, the less certain they can be about its momentum; and, the closer they come to measuring its momentum, the less certain they can be about its position. Pagels writes,

What the Heisenberg uncertainty relation asserts is that it is impossible to build an apparatus for which the uncertainties so calculated, over a large series of measurements, fail to obey the requirement that the product of uncertainties, (Δp) x (Δq), is greater than or equal to Planck’s constant h .⁴⁶

The uncertainty relation, as Bohr points out, illustrates the complementary nature of quantum mechanics because one cannot know an object’s position and momentum simultaneously, thus leading to ‘uncertainty’ that can be addressed only through statistics. Pauli, who was instrumental in developing the uncertainty relations,

⁴⁴ Bohr, *Atomic Theory and The Description of Nature* 58-59.

⁴⁵ Bohr, *Atomic Theory and The Description of Nature* 63.

⁴⁶ Pagels, *The Cosmic Code* 70.

described the uncertainty relations best when he wrote, “One can look at the world with the p-eye and one can look at it with the q-eye but when one would like to open both eyes, one gets dizzy.”⁴⁷

Using the complementarity metaphor to invent a description of Heisenberg’s uncertainty relation, Bohr more or less creates another new metaphor, ‘physics is uncertain’ to replace the metaphors ‘physics is certain’ and ‘physics is objective’ that relied on the classical concept of causality. As a metaphor, the uncertainty relation introduces to descriptions of phenomena a fundamental indeterminacy that suggests that the classical ideals of ‘certainty’ or ‘objectivity’ in physics are unattainable. Bohr points out that it was often assumed in classical physics that one could, given a ‘certain’ set of measurements, determine unambiguous information concerning the previous or future behavior of an object.⁴⁸ In quantum mechanics, however, the interaction of the agent with the phenomenon inevitably changes the state of the system. Therefore, one of the implications of this ‘uncertainty’ metaphor—a critical one for physics—is that observers cannot be independent of phenomena, or objective, because their attempt to observe an aspect of a phenomenon (e.g. its momentum or position) unavoidably changes the state of the system.⁴⁹ In other words, the ‘interaction’ of the observer with the observed is unavoidable, and as Bohr says, “our knowledge of the position after observation nevertheless will be affected by an uncertainty.”⁵⁰ Indeed, Bohr points out that reconceiving physics as uncertain or indeterminate redefines the relationship of

⁴⁷ Quoted in Pais, *Niels Bohr’s Times* 304.

⁴⁸ Bohr, *Atomic Theory and The Description of Nature* 68.

⁴⁹ Werner Heisenberg, *Physics and Philosophy* (New York: Harper & Row, 1958) 50.

⁵⁰ Bohr, *Atomic Theory and The Description of Nature* 65.

physicists and their experimental apparatus with phenomena.⁵¹ Holton illustrates this result of quantum mechanics when he writes,

When you ask, “What is light?” the answer is: the observer, his various pieces and types of equipment, his experiments, his theories and models of interpretation, and whatever it may be that fills an otherwise empty room when the light bulb is allowed to keep on burning. All this, together, is light.⁵²

Moreover, Nobel physicist Pagels writes that “the Copenhagen interpretation maintains that if we look closely at the world—at the level of atoms—then its actual state of existence depends in part on how we choose to observe it and what we choose to see.”⁵³

To sum up at this point, in his 1927 Copenhagen interpretation lecture Bohr introduces a new dominant metaphor, ‘nature is complementary’ to succeed the dominant metaphor of classical physics ‘nature is causal.’ As a dominant metaphor, complementarity becomes the basis of invention for the remainder of Bohr’s argument and, later, arguments in quantum mechanics. In the last parts of his lecture, Bohr illustrates the value of the complementarity metaphor by using it to invent explanations of several stubborn theoretical paradoxes—most notably Heisenberg’s uncertainty relations and the wave-particle duality of light and matter—that had been tormenting the discipline of physics. Bohr also argues that a renunciation of causality from classical physics also urges a renunciation of classical notions of objectivity and certainty that are brought about by a causal point of view. Instead, Bohr claims, in quantum mechanics, one should develop explanations of phenomena in terms of a second new metaphor,

⁵¹ Bohr, *Atomic Theory and The Description of Nature* 67.

⁵² Holton, *Thematic Origins of Scientific Thought* 104.

⁵³ Pagels, *The Cosmic Code* 114.

'physics is uncertain,' leaving aside classical notions of objectivity, certainty, and causality.

Renouncing Classical Physics

With little doubt, Bohr's argument in the 1927 Copenhagen Interpretation lecture was extremely complex. Moreover, understanding the lecture itself was not aided by Bohr's infamous ability to make his lectures confusing. After hearing Bohr repeat the Copenhagen Interpretation lecture at the 1927 Solvay conference, Paul Ehrenfest, while enthusiastic about Bohr's argument, wrote back to his graduate students, "Once again that awful Bohr incantation terminology. Impossible for anybody else to summarize."⁵⁴ Much of Bohr's career after 1927 was spent clarifying and deepening the somewhat unfinished understanding of complementarity he offered in the Copenhagen Interpretation lecture.

Despite its complexity, however, I believe in Bohr's lecture we witness clearly the introduction of a new dominant metaphor, 'nature is complementary' that still more or less forms the basis of invention for arguments in quantum mechanics. Moreover, we witness the introduction of 'complementarity' as a metaphor that Bohr believed would create a "general point of view" through which the discipline of physics itself could be successfully reconceptualized. Dominant metaphors, as discussed in chapter two, shape the way scientists interpret and discourse about natural phenomena. Indeed, as Burke asks in *Permanence and Change*, "are we not coming to see that whole works of scientific research, even entire *schools*, are hardly more than the patient repetition, in all its ramifications of a fertile metaphor?"⁵⁵ Dominant metaphors—"fertile metaphors" as Burke calls them—seem to offer enduring perspectives that guide not only how one

⁵⁴ Quoted in Pais, *Niels Bohr's Times* 312.

⁵⁵ Burke, *Permanence and Change* 95.

talks about nature but also how one interprets and conceptualizes reality. Or, as Lakoff and Johnson suggests, these metaphors are ones “we live by,” organizing and shaping the beliefs of a community while inviting various interpreters to view situations from similar perspectives. These metaphors become so ingrained in the way humans live their lives that they, as Lakoff and Johnson claim, “structure how we perceive, how we think, and what we do.”⁵⁶ Moreover, Lakoff and Johnson note that some dominant metaphors become such an integral part of a culture that they shape thought and speech “in ways we are hardly ever conscious of.”⁵⁷ Indeed, in science, some metaphors like ‘nature is a machine,’ ‘nature is an organism,’ ‘nature is God’s divine creation,’ or ‘nature is evolutionary’ take on this dominant role, guiding the way whole schools or scientific movements conceptualize reality and invent theories to explain nature.

By developing complementarity as a new dominant metaphor for quantum mechanics in his 1927 Copenhagen Interpretation lecture, Bohr more or less challenged the rational basis of physics itself. To most Western physicists, at least since Aristotle’s time, nature was assumed to be a monolithic whole that ultimately engendered “one” absolute truth. Therefore, Aristotle and generations of natural philosophers and scientists after him presumed there to be only one correct lexicon for describing, knowing, and conceptualizing nature.⁵⁸ Others lexicons thus were assumed to be distorted, flawed, or somehow inaccurate because they did not perfectly reflect the certain truth that lay hidden beneath the movements of nature. So, Bohr’s suggestion that reality not only could be described in contradictory ways but also *must* be described in contradictory ways was quite novel. In a sense, the notion that ‘nature is

⁵⁶ Lakoff and Johnson, *Metaphors We Live By* 4.

⁵⁷ Lakoff and Johnson, *Metaphors We Live By* 5

⁵⁸ Richard Harvey Brown, “Rhetoric and the Science of History: The Debate Between Evolutionism and Empiricism as a Conflict of Metaphors,” *Quarterly Journal of Speech* 72 (1986) 148.

complementary' challenged the rationality of classical physics at a core level by suggesting that one absolute description of nature was ultimately unattainable. Consequently, Bohr argued, opposing, or complementary, descriptions of reality needed to be inevitably brought into antithetical relationships to provide a more comprehensive understanding of nature.

Interestingly, Bohr suggested that complementarity was warranted by the "nature of the quantum theory" itself.⁵⁹ Recognizing the importance of the recurring paradoxes created by the quantum theory, Bohr interpreted the contrastive features of his rhetorical situation and created a metaphor to address them. Specifically, the complementarity metaphor was a broader interpretation of Einstein's and de Broglie's claims that light and matter exhibit a dualistic behavior that exhibits both wave-like qualities and particle-like qualities. Einstein and de Broglie assumed, however, that these frustrating paradoxes would ultimately be resolved in favor of a synergy of both interpretations. Quite differently, Bohr came to interpret this wave-particle duality as "complementary" and thus, to use Rorty's phrase, the new metaphor developed into "a call to change one's language and one's life, rather than a proposal about how to systematize either."⁶⁰ Once he embraced the perspective offered by the metaphor, Bohr was then able to reinterpret his beliefs about quantum physics from a quite different point of view that was completely foreign to classical physics.

What makes Bohr's invention of the complementarity metaphor unique is that he essentially couples dominant metaphors from classical physics and then uses this coupling to invent an argument that challenges classical physics itself. Whereas in classical physics only one "absolute" or "final" description would have been acceptable,

⁵⁹ Bohr, *Atomic Theory and The Description of Nature* 55.

⁶⁰ Rorty, *Essays on Heidegger and Others* 13.

Bohr suggested that physicists can legitimately view phenomena (i.e. light, electrons) as “waves” or “particles” despite the fact that these opposing descriptions of reality—invented through the metaphors ‘light/electron is a wave’ or ‘light/electron is a particle’—inevitably exclude each other. Therefore, neither description can be folded into the other to invent one final description of a particular event. Bohr argued that the quantum postulate itself enforces this pluralistic interpretation of reality by creating a “peculiar indeterminacy” that neither description of a phenomenon alone can resolve. Essentially, each complementary metaphor urges a different interpretation of reality that complements but also excludes the other. Nevertheless, both points of view (wave and particle) are needed to develop a broader rational account (*logos*) of the behavior of nature. Indeed, each perspective can be seen as an individual *logos* of its own that only offers a partial interpretation of the entire situation. Complementary scientific metaphors encourage different perspectives, leading to paradoxical interpretations of the behavior of a phenomenon.

The metaphor ‘nature is complementary,’ therefore, invited Bohr and other physicists to radically change the point of view from they interpreted their experiences with reality. Complementarity urged them to invent their descriptions of phenomena and theories through the tacit assumption that reality is ultimately paradoxical and antithetical. This change in perspective was no doubt a significant one, but, as Bohr claimed, the notion of complementarity was ultimately one of the broader implications the quantum metaphor, ‘nature is discontinuous,’ itself. He points out that the quantum postulate “is completely foreign to the classical theories,” hinting that the lack of harmony in the physics community was due to a fundamental conflict between the perspectives urged by the quantum metaphor and the basic concepts that guided

classical descriptions of nature.⁶¹ In a sense, this large assertion, one that the majority of his audience probably accepted, implied that the basis of classical physics was somehow incomplete or even flawed because it was incapable of explaining the paradoxes of quantum physics. So, by the time Bohr announced rather directly that “this [quantum] postulate implies a renunciation as regards the causal space-time coordination of atomic processes,”⁶² he had already established a basis from which the idea, even the necessity, of this sort of complete renovation became an avenue worth considering.

Bohr then used this new complementarity metaphor to invent the argument in the 1927 Copenhagen Interpretation lecture, thus urging a dislodging of the basis of classical physics itself. Recognizing that classical ideals of objectivity and certainty were no longer tenable from the perspective offered by the notion that ‘nature is complementarity,’ he could then replace them with the idea that ‘physics is uncertain.’ Moreover, the classical notion that nature is strictly ‘causal’ then became suspect in descriptions of atomic phenomena. In quantum physics, Bohr argued, paradox and uncertainty became expected features of reality. If anything, Bohr seemed to suggest, the complementarity metaphor offered a final ‘turn’ in which the basis of classical physics was at last abandoned in favor of a new complementary theory of quantum mechanics. The metaphor urged physicists to renounce classical concerns about causality, objectivity, and certainty that made the quantum theory seem peculiar. Meanwhile, the complementarity metaphor offered an alternative point of view from which to reconceive reality and the relationship of physicists to that reality. Indeed, Bohr saw the complementarity metaphor as only a starting place from which the

⁶¹ Toulmin, *Human Understanding* 53.

⁶² Bohr, *Atomic Theory and The Description of Nature* 53.

broader theory of quantum mechanics could then evolve. Essentially, Bohr's complementarity metaphor became the basis of invention for arguments in quantum mechanics.

I believe Bohr deliberately introduced the complementarity metaphor, 'nature is complementary' as a dominant metaphor to serve as the basis of a "general point of view," or perspective, that he believed would harmonize the discipline of physics. As he fully recognized, though, the general point of view brought about by the complementarity metaphor called for a large-scale reconceptualization of nature and the discipline of physics. Even Bohr realized that his argument in the 1927 Copenhagen Interpretation lecture offered only the first crude steps toward a comprehensive interpretation of reality through quantum mechanics.

Conclusions

In this chapter, I have used metaphorical analysis to illuminate the emergence of two profound metaphors, 'nature is complementary' and the subsequent 'physics is uncertain,' that form the basis of quantum mechanics. It should be pointed out, however, that the implications of these metaphors are still a matter of some debate among scientists and philosophers. As one might expect, the dramatic conceptual change urged by these metaphors led to a great amount of resistance in the scientific community. Einstein immediately saw the implications of complementarity and reacted in a way that was uncharacteristically hostile. He wrote to Schrodinger on May 31, 1928:

The Heisenberg-Bohr tranquilizing philosophy—or religion?—is so delicately contrived that, for the time being, it provides a gentle pillow for the true believer

from which he cannot very easily be aroused. So let him lie there. . . But this religion has so damned little effect on me.⁶³

Like many physicists, Einstein was unwilling to accept an indeterminate and complementary interpretation of reality. He believed the complementary nature of the Copenhagen interpretation was, if anything, proof that quantum mechanics was still incomplete. Indeed, complementarity and uncertainty in various forms became the sources of contention over which Einstein and Bohr spent much of their scientific lives arguing. In his famous essay, "Discussion with Einstein on Epistemological Problems in Atomic Physics," Bohr hints at their dynamic relationship when he states, "I have so-to-speak, been arguing with Einstein all the time, even in discussing topics apparently far removed from the special problems under debate at our meetings."⁶⁴ Neither scientist ever swayed the other.

Months before Einstein's death, Heisenberg went to visit him at Princeton. The following passage by Heisenberg illustrates perfectly the different point of view brought about by Bohr's introduction of the complementarity metaphor:

Einstein's whole interest was focused on the interpretation of quantum theory which continued to disturb him. . . At bottom, indeed, the difference between the two viewpoints lay somewhat deeper. In his earlier physics, Einstein could always set out from the idea of an objective world subsisting of space and time, which we, as physicists, observe only from the outside, as it were. The laws of nature determine its course. In quantum theory this idealization was no longer possible. Here the laws of nature were dealing with temporal change of the possible and the probable. But the decisions leading from the possible to the

⁶³ Einstein to Schrodinger, May 31, 1928. Reprinted in Przibram, *Letters on Wave Mechanics*.

⁶⁴ Niels Bohr, *Atomic Physics and Human Knowledge* (New York: Science Editions, 1958) 66.

actual can be registered only in statistical fashion, and are no longer predictable. With this conception of reality in classical physics is basically undermined, and Einstein could no longer adjust himself to so radical a change.⁶⁵

In conclusion, Bohr's complementarity metaphor is both perplexing and extraordinary because it seems to urge a completely new perspective toward reality that is foreign to the general aspirations of Western science. Conceptualizing natural phenomena as 'complementary' urges scientists to conceive of reality in antithetical, probabilistic, and non-causal terms while renouncing the certain, deterministic, or causal arguments that have been used since Aristotle. Holton writes, "The consequence Bohr drew from these recognitions was of a rare kind in the history of thought: he introduced explicitly a new thema, or at least identified a thema that had not yet been consciously a part of contemporary physics."⁶⁶ Indeed, the argument in Bohr's 1927 Copenhagen Interpretation speech is interesting because it is not logical or methodological in a way that would have been acceptable to classical physics. The argument is at its roots metaphorical. To those who refuse to accept the dominant metaphors at the heart of the Copenhagen interpretation, the arguments invented from the perspective it urges seem patently false and even absurd.⁶⁷ To those who embrace the metaphor, however, its implications are profound.

⁶⁵ Werner Heisenberg, *Encounters with Einstein* (Princeton: Princeton UP, 1983) 121-122.

⁶⁶ Holton, *Thematic Origins of Scientific Thought* 117.

⁶⁷ It is notable that Nobel physicist Richard Feynman suggests that Nature is just "absurd from the point of view of common sense." See Richard Feynman, *QED: The Strange Theory of Light and Matter* (Princeton: Princeton UP, 1985) 10.

CHAPTER SIX IMPLICATIONS AND CONCLUSIONS

Every theory of the universe should have in it the fundamental statement "This is not a universe."

David Bohm
F. David Peat

Metaphor, as I have illustrated in this study, plays an important role in the invention of scientific arguments. I have shown how metaphors, especially "emergent" metaphors, bring concepts into contrast, urging scientists to adopt novel perspectives toward their beliefs and inviting them to develop new ways of conceptualizing and discoursing about nature. I have also shown that metaphors serve a constitutive function in scientific discourse by temporally acting as "dominant" or "root" metaphors that guide entire schools of scientific thought or by serving as "dead" metaphors that make up the scientific lexicon. With this view, metaphors can be understood to serve an integral role in scientific discourse, not merely an ornamental or stylistic role. Indeed, I believe it is impossible for scientists to do without metaphor, because the beliefs scientists take to be "scientific knowledge" are dependent more or less on discourse that is grounded and shaped by metaphoric words and phrases. Or, as I.A. Richards points out, "our pretense to do without metaphor is never more than a bluff waiting to be called."¹

Nevertheless, this argument that metaphors play an active, constitutive role in scientific discourse is not new. Rhetoricians have already done a fair amount of work toward identifying and clarifying the role of metaphor in scientific communication and theory building. My approach in this study, however, has differed from other rhetorician's views of scientific metaphor because I have stressed the "interpretive" or

¹ Richards, *The Philosophy of Rhetoric* 92.

“hermeneutic” role of metaphor in the invention of scientific arguments. Quite differently, other rhetoricians have been concerned with the supposed *causal* nature of metaphors in which words “interact” in ways that lead to new insights or even paradigm shifts. My argument has been that metaphors themselves do not cause conceptual change in science. Rather, scientists’ *interpretations* of metaphors within particular contexts urge members of the scientific community to develop new ways of conceptualizing and discoursing about nature. As such, I have argued that new metaphors in scientific discourse are a natural consequence of scientists’ attempts to explain and describe physical and social situations that are inevitably undergoing change. Indeed, as Bohm and Peat argue, the act of “doing science” naturally brings concepts into contrast, spinning off new metaphors that are used to discourse about nature. It is the interpretation of these metaphors that lead to new movements in science.

What implications does this “interpretive” view of metaphor have for scientific discourse, scientific activities, and our understanding of the rhetoric of science? This is not an easy question to answer. Nevertheless, these sorts of questions are ones that rhetoricians should address if research in the “rhetoric of science” is to be constructive and meaningful to the disciplines of rhetoric and science. In this concluding chapter I will discuss the implications brought out by the preceding analyses of metaphor in the seminal texts of the quantum theory. My aim is to show that studies of metaphor in scientific texts lead not only to a better understanding of the rhetoric of science but also a greater understanding of science itself. Overall, I believe an awareness of the role of metaphor in scientific discourse allows us to illuminate texts and illustrate how scientists invent many of Western culture’s beliefs about nature.

Implications for Research in the Rhetoric of Science

My study of the seminal texts of the quantum theory appears to contribute to our understanding of the role and function of metaphor in the emergence of theoretical movements in modern physics. To this point, scholars like Black, Hesse, Rothbart, Peterfreund, MacCormac, and others have also argued that metaphors play a central role in scientific discourse; however, these scholars have typically been satisfied with a highlighting of important metaphors in the lexicon of science. Therefore, they have concentrated on proving that scientific discourse is saturated with metaphoric words and phrases. In the end, like warriors touching their adversary for the sake of honor alone, these scholars have shown that scientists cannot eschew or ignore the so-called “literary” or “figurative” features of discourse. Going a few steps further, my study has explored scientists’ use of metaphors to *invent* the beliefs and arguments that form the content of scientific theories. Whereas other scholars have illustrated the pervasiveness of metaphor in science, I have shown how scientists use metaphors as “interpretive” devices to guide in the invention of new beliefs and new ways of discoursing about nature.

One implication of this study is that it illuminates the importance of metaphors as “constitutive” features of scientific discourse. For decades, rhetoricians have recognized the importance of metaphor as a constitutive feature in scientific discourse, but few have closely analyzed texts to illustrate how metaphors actually guide scientific movements and make up the scientific lexicon. By offering text-based evidence for the constitutive nature of scientific metaphor, my study has provided support for Kenneth Burke’s claim that metaphors form the basis for entire schools of scientific thought. I have used my analyses of the seminal works of the quantum theory to illustrate that metaphors, as Burke pointed out, change one’s perspective, urging one to see

“something *in terms* of something else.”² So, for example, when Kepler argued in the sixteenth century that the ‘universe is a machine’ or when Harvey claimed that the ‘heart is a pump,’ they indeed used metaphors as devices to invite scientists, including themselves, to see something (i.e. the universe, the heart) in terms of something else (i.e. a machine, a pump). I have shown that once scientists embrace an “emergent” metaphor, like ‘the universe is a machine,’ the metaphor then serves as a device for viewing or interpreting natural phenomena from a new perspective.

It is important, however, for rhetoricians of science to recognize that scientific metaphors do not serve an analogy-like function in scientific arguments. In other words, Kepler was not arguing that the universe is “like a machine,” nor was Harvey suggesting that the heart is “like a pump.” Rather, they were claiming that ‘universes’ and ‘hearts’ *are* ‘machines’ and ‘pumps.’ Consequently, when one closely analyzes scientific texts, as I have done in the previous three chapters, it soon becomes apparent that it is impossible to communicate beliefs about nature without using metaphors. For example, can we describe the human heart in terms that avoid the ‘heart is a pump’ metaphor? We are accustomed to describing the features and functions of the heart in terms of “valves,” “arteries,” “flow,” and “circulation.” These lexical terms are all extensions of the ‘heart is a pump’ metaphor, and we would have a hard time doing without them. Indeed, the metaphor ‘heart is a pump’ itself *is* the literal language with which we describe and discourse about the heart. The use of a metaphor does not merely aid us in talking about the heart, it unavoidably *constitutes* the way we interpret, conceptualize, and describe the heart’s features and functions.

I believe this “constitutive” function of metaphor in scientific discourse opens important new avenues of research in the rhetoric of science. In my rhetorical analyses

² Burke, *Grammar of Motives* 503.

of the quantum theory papers of Planck, Einstein, and Bohr, I have shown how metaphors, especially the quantum metaphor, played this constitutive role in the development of modern physics. After its introduction by Planck, the quantum metaphor gradually became a dominant feature of these physicists' beliefs, influencing the way they interpreted the behavior of atomic phenomena and urging them to develop concepts and descriptions that relied on inherent discreteness in nature. In essence, the metaphor itself shaped these scientists' interpretations of their experiences with nature, inviting them to develop theories that were radically different than those of classical physics. What I have shown in my analyses of these physicists' texts is that the idea of a "quantized" reality, as Lakoff and Johnson might point out, became a metaphor that Planck, Einstein, and Bohr "lived by." The quantum metaphor went far beyond a convenient way to talk about nature: It became a constitutive means through which these physicists interpreted and conceptualized their experiences with atomic phenomena. On a broader scale, I believe other documents in the rhetoric of science can be interpreted through this kind of metaphorical analysis.

A second implication of my study to research in the rhetoric of science is the close relationship it stresses between scientific metaphor and the invention of scientific arguments. Alan Gross in *The Rhetoric of Science* suggests, I think correctly, that "from a rhetorical point of view, scientific discovery is properly described as invention."³ In my studies of the works of Planck, Einstein, and Bohr, we see how metaphors can form the *basis of invention* for scientific arguments by offering new perspectives from which scientists interpret nature. By inviting scientists to regard natural phenomena in "new ways," metaphors can serve as starting places for the invention of arguments that expound new ways of conceptualizing and discoursing

³ Gross, *The Rhetoric of Science* 6-7.

about nature. However, as Stephan Toulmin points out, a new perspective is only the origination point for the development of new theories. Toulmin argues that once scientists adopt “new ways of regarding old phenomena,” they must then answer the question “what sort of demonstration will justify us in agreeing that, whereas this was not previously known, it can now be regarded as known?”⁴ And indeed, my study shows that this move toward rhetorical invention seems to be what happens when scientists interpret natural phenomena from the new perspectives created by metaphors. For example, when Kepler wrote “I aim to show that the celestial machine is to be likened not to a divine organism but to a clockwork,” the issue was by no means settled in Kepler’s favor.⁵ Instead, his ‘universe is a machine’ metaphor was only the starting place for the invention of arguments that expounded this new way of discoursing about nature. This “fertile” metaphor, as Burke might call it, eventually served as a premise for the entire mechanism school of physics, offering a basis from which mechanistic descriptions and theories of nature were invented.

In regards to the invention of arguments in modern physics, my studies of the works of Planck, Einstein, and Bohr illustrate how metaphors, specifically the quantum metaphor and the complementarity metaphor, served as a basis of invention for the seminal papers of the quantum theory and quantum mechanics. In his 1900 light quanta paper, Einstein argued that Planck’s ‘energy is quantized’ claim can be considered “independent of his theory of ‘black radiation.’”⁶ In making this crucial observation, Einstein recognized that the quantum metaphor invited one to conceptualize energy-related phenomena, specifically light, in a way that violated the tenets classical physics.

⁴ Toulmin, *The Philosophy of Science* 17.

⁵ Quoted in Kearney, *Science and Change* 144.

⁶ Einstein, “Concerning a Heuristic Point of View about the Creation and Transformation of Light” 547.

He then interpreted the implications of the quantum metaphor, using the metaphor itself as a guide toward inventing his argument that light must be quantized. Indeed, Einstein's argument for a new "heuristic point of view about the creation and transformation of light" is an exploration of the implications for light of the quantum metaphor. Twenty years later, in the 1927 Copenhagen lecture, Bohr employed both the quantum metaphor and the complementarity metaphor to invent his argument for the Copenhagen interpretation, a radical new way of conceptualizing and discoursing about atomic phenomena. Essentially, these two metaphors, 'nature is quantized' and 'nature is complementary' formed not only the basis of invention for his 1927 lecture but also the basis of what Bohr calls a "general point of view ... [which] will be helpful in order to harmonize the apparently conflicting views taken by different scientists."⁷

Demonstrating the usefulness of the complementarity metaphor to physics, Bohr used the 1927 Copenhagen Interpretation lecture to recast the quantum theory and the discipline of physics into terms that are brought about by the implications of the complementarity metaphor. In other words, he used the metaphor to invent an argument that illustrated how the quantum and complementarity metaphors urged physicists to reconceptualize nature into complementary terms.

For rhetoricians of science, I believe this fundamental link between scientific metaphor and the invention of scientific arguments is crucial to rhetorical research in the sciences. Traditional rhetoricians like Melia, McGuire, and Kinneavy have long suggested that rhetorical analysis cannot delve into the full depths of science because it cannot explain the so-called "content" of science. And yet, in my study, we see how physicists like Planck, Einstein, and Bohr used metaphors as a basis for *inventing* the content of science. Indeed, much as Toulmin claims, "discoveries" in science typically

⁷ Bohr, *Atomic Theory and the Description of Nature* 52.

emerge when scientists see old phenomena in new ways. From a rhetorical point of view, metaphors are the devices through which these “new ways” or new perspectives come about. If I am correct, this view of the role of scientific metaphor in the invention of scientific beliefs and theories allows us to research the so-called “terra incognita” that Melia and others have tried to exclude from rhetoricians of science.

A third implication of my study for rhetoricians of science is the importance of interpretation with regards to scientific metaphor. As mentioned previously, rhetoricians who study scientific metaphors have focused primarily on the supposed “causal” nature of metaphorical phrases. Scholars like Hesse, Black, Rothbart, and others have suggested that the words in a metaphoric phrase “interact” in a way that cause scientists to experience a change in beliefs. And, indeed, on the surface it may appear to many scholars that metaphors are the causal force behind the development of new scientific theories, because Western philosophy since Aristotle has typically viewed change, including conceptual change, as the result of some causal agent. Therefore, it might seem only natural to conclude that metaphors like the ‘universe is a machine’ or ‘nature is quantized’ somehow caused people to think and talk differently by creating a special meaning or flash of insight.

However, my study of the seminal texts of the quantum theory shows that this “interaction” view of metaphor does not hold up when one looks closely at the way metaphors are employed in scientific texts and the way they work their way into the beliefs of the scientific community. In Planck’s text, for example, the metaphor ‘energy is discontinuous,’ or ‘energy is quantized,’ went mostly unnoticed by Planck and his contemporaries. If this metaphor had caused some “flash of insight” in Planck or Planck’s readers, then one would expect to see some sort of immediate reaction by these scientists. Instead, the quantum metaphor went relatively unnoticed for five years and only came into prominence eight years later. Therefore, it seems obvious that the

quantum metaphor did not have an “a ha!” or “eureka!” effect on scientists that Gerhardt and Russell suggest should occur when scientists first develop new metaphors. Nor did the quantum metaphor seem to immediately create a new schema or paradigm through which Planck entered a new world or a new, incommensurable conceptual structure. Rather, it was only when Einstein and others began to *interpret* the implications of Planck’s quantum metaphor that it gained an increasingly prominent role in physics.

Indeed, my study seems to suggest that most rhetoricians who study scientific metaphors have the whole situation backwards. A new metaphor does not cause scientists to think and talk differently; rather, when scientists interpret the implications of a particular metaphor (i.e. they see something in terms of something else) they are then urged to invent arguments and theories that illustrate the usefulness of the perspective offered by the metaphor. In other words, the metaphor itself does not change scientists’ world views or conceptions of nature; it only serves as a starting place for scientists themselves to start thinking and talking differently about nature. Therefore, I believe scientists’ interpretive acts, not metaphors, are the agents of change in scientific beliefs. Though metaphors are essential, constitutive features of scientific discourse, they are only devices that invite, not impel, scientists to see things from particular perspectives.

I believe this interpretive view of scientific metaphors is in line with the broader “hermeneutic” or “interpretive” movement in modern rhetorical theory. One of the flag bearers of this movement, Timothy Crusius, writes that “All rhetorical acts are also and irreducibly hermeneutical acts.”⁸ He also claims that “interpretation is equally significant in even the most straightforward and disinterested presentation of ‘the facts’

⁸ Timothy Crusius, *A Teacher’s Introduction to Philosophical Hermeneutics* (Urbana, Ill.: NCTE, 1991) 53.

about any subject matter.”⁹ As Crusius points out, to use language is to put oneself in an interpretive stance in which the meanings of utterances is ultimately reliant on an interpreter. Another flagbearer of this movement, Thomas Kent, writes, “we put language to use—language does not use us—when we employ it to interpret the utterances of others, objects in the world, and even our own utterances.”¹⁰ Indeed, I believe emergent scientific metaphors, like other forms of discourse, put scientists into an interpretive relationship that invites them to view natural phenomena differently than they had prior to the metaphor. But, much as Kent points out about language in general, a metaphor does not “use” the scientist by *causing* a conceptual change; rather, scientists’ interpretations of the implications of the metaphor bring about the conceptual change. If I am correct, this “interpretive” view of scientific metaphor explains why Planck did not originally recognize the significance of the quantum metaphor while Einstein did. The quantum metaphor did not cause a conceptual change by creating an ontological flash, a special meaning, or insight into reality. Instead, Einstein’s interpretation of the implications of Planck’s inadvertent metaphor and his subsequent invention of an argument for light quanta led ultimately to the “quantum” view of nature.

Overall, potentially the most important implication of this study—and perhaps the least adequately explored issue in this dissertation—is the possibility of a “sophistic” view of the rhetoric of science. As discussed in chapter two, the sophistic tradition in ancient and modern rhetoric suggests a hermeneutic or interpretive understanding of discourse. Sophistic rhetoric assumes that speakers and writers are inevitably thrown into a changing reality in which they must use language to interpret

⁹ Crusius, *A Teacher’s Introduction to Philosophical Hermeneutics* 53.

¹⁰ Kent, *Paralogic Hermeneutics* 16.

and influence their physical and social situations. Consequently, metaphors, including scientific metaphors, can be understood to be a natural linguistic response to a reality and a language that is undergoing change. In other words, as speakers use language to describe and theorize about their changing physical and social situations, they use metaphors to come to terms with situations in which concepts are continually being brought into contrast. A metaphor urges a “turn” in one’s beliefs, inviting the interpreter of the metaphor to view, talk about, and experience reality in a new way.

I believe this sophistic approach to rhetoric of science offers a new way for rhetoricians to analyze and interpret scientific text. Rhetoricians of science have previously discussed interpretation and the invention of scientific theories in terms of neo-classical concepts like *topoi* or stasis theory. These neo-classical approaches, while appropriate under certain conditions, implicitly assume that the rhetor, or scientist, is actually looking for stable contextual patterns in reality that can then be used to develop arguments. Quite differently, to view the invention of scientific arguments in terms of sophistic rhetoric recognizes that arguments come about when scientists attempt to interpret the contrasts in nature that make up their physical and social situations. This view assumes that reality, nature, the passing show is inevitably in flux, creating contrasts that scientists attempt to explain. In essence, a sophistic view of scientific discourse suggests that scientists are always inventing new explanations for nature through metaphors because they are inescapably immersed in a physical and social situation that is changing and thus bringing once unrelated concepts into contrast.

Nevertheless, my study, due to its concentration on metaphor and invention, has only explored one limited possibility for research that employs sophistic rhetoric to analyze scientific texts. And, this dissertation, admittedly, has not shown in any conclusive way that sophistic rhetoric offers a useful avenue for research in the rhetoric of science. But, I think this study offers a start in that direction. What I have tried to do

is to look at scientific texts through a sophistic/hermeneutic lens to see the way in which metaphors played a role in the invention of modern physics. In a broader sense, though, I believe this sophistic interpretation of the rhetoric of science offers an alternative to the rather realist or sometimes relativist analyses that come about through neo-classical approaches to the rhetoric of science. As with many starts in new directions, however, only further research will show whether this new area of research is fruitful.

Conclusion: The Challenge of the Rhetoric of Modern Physics

In the end, I believe modern physics offers rhetoricians one of their greatest challenges. It is a challenge that was laid out by Bohr himself. Bohr's biographer and friend, Abraham Pais, writes, "The language of science, more generally the ways in which we communicate—these were the themes on which Bohr focused in the Como lecture and for the rest of his life."¹¹ Indeed, both Bohr and Heisenberg spent much of their post-1927 efforts toward developing productive ways to talk about this strange "quantum reality" that the Copenhagen interpretation of quantum mechanics seemed to describe. Much later, however, Heisenberg was to concede that perhaps the proper language for talking about quantum mechanics had not yet been developed.¹²

As Bohr and Heisenberg recognized early on, language was and has proven to be one of the most troublesome issues in the continuing development of modern physics. Bohm and Peat, both modern quantum physicists, suggest that many of the present-day problems in today's physics community can be attributed to the inability of scientists to "engage in free play, unimpeded by rigid attachments to particular points of view."¹³ They believe that the lack of a bridge between the theory of relativity and

¹¹ Pais, *Niels Bohr's Times* 314.

¹² Heisenberg, *Physics and Philosophy* 167.

¹³ Bohm and Peat, *Science, Order, and Creativity* 87.

quantum mechanics is due to the fact that there is “now no common, informal language that covers them both.”¹⁴ Moreover, “Even within the quantum theory itself there is a serious failure of communication between the various interpretations.”¹⁵ These problems, Bohm and Peat suggest can be overcome by paying attention to language issues. They write,

it is suggested that science will flourish in a more creative way if it allows a diversity of different theories to flourish. When communication between these different points of view is free and open, so that a number of alternatives can be held together at the same time, then it is possible to make new creative perceptions within science. What is proposed is not so much a proliferation of views along with their individual supporters, but rather a *unity of diversity*.¹⁶

In this study, I have attempted to develop and employ but one among many possible approaches through which rhetoricians can productively talk about the way language is used in science. I suspect, as Bohm and Peat do, that many of the dilemmas and complexities of physics are seated in the overly rigid rhetorical techniques scientists employ to argue for their beliefs. After all, discussing a quantum reality will always be difficult if, as Rorty claims,

In our culture, the notions of “science,” “rationality,” “objectivity,” and “truth” are bound up with one another... We tend to identify seeking “objective” truth with “using reason,” and so we think of the natural sciences as paradigms of rationality. We also think of rationality as a matter of following procedures laid

¹⁴ Bohm and Peat, *Science, Order, and Creativity* 85.

¹⁵ Bohm and Peat, *Science, Order, and Creativity* 86.

¹⁶ Bohm and Peat, *Science, Order, and Creativity* 83.

down in advance, of being “methodological.” So we tend to use

“methodological,” “rational,” “scientific,” and “objective” as synonyms.¹⁷

Ironically, lessons learned from the history of the quantum theory and the Copenhagen interpretation itself seem to urge us away from this understanding of science. And yet, one need only read the coverage of science in newspapers or turn on the television to see that many people in our culture, including scientists, still assume these criteria determine what is ‘scientific’ and what isn’t.

Unfortunately, I believe Bohr’s important but subtle emphasis on the significance of language in quantum mechanics has gone mostly unnoticed in the philosophical struggle that has developed in the wake of the Copenhagen interpretation. In application, the success of quantum mechanics is unquestioned. It has opened amazing paths toward understanding light, matter, and the inner workings of atoms. However, like a Faustian contract, it calls on physics to abandon Western science’s traditional attempt to discover the absolute truth about an objective reality that is independent of human interpretation. From Einstein until present day, a good number of scientists have resisted or mostly ignored this side of quantum mechanics.¹⁸ As physicist Steven Weinberg writes,

It is truly surprising how little difference all this makes. Most physicists use quantum mechanics every day in their working lives without needing to worry about the fundamental problem of its interpretation.... So irrelevant is the philosophy of quantum mechanics to its use, that one begins to suspect that all

¹⁷ Rorty, *Objectivity, Relativism, and Truth* 35.

¹⁸ Polkinghorne points out that “scientists feel that they are right to take a philosophically realist view of the results of their researches; to suppose that they are finding out the way things are.” Polkinghorne, *The Quantum World* 2-3. Weinberg’s *Dreams of a Final Theory* is a well reasoned defense of a form of scientific realism. He argues that a “final theory” is still the goal of modern physics. See Weinberg, *Dreams of a Final Theory*.

the deep questions about the meaning of measurement are really empty, forced on us by our language, a language that evolved in a world governed very nearly by classical physics.”¹⁹

Unlike Weinberg, though, Bohr, Heisenberg, and Einstein believed the problem of its interpretation, especially with regards to the language of science, was central to quantum mechanics.²⁰ However, I find it ironic and a bit telling that Weinberg puts his finger on the issue that Bohr spent much of his life pursuing—how a language and lexicon, inherited from an absolutist classical physics, will or will not suit the needs of quantum mechanics. Weinberg’s opinion also suggests that perhaps Bohr’s concerns about the language of science have not been adequately addressed.

Though still a young field, rhetoric of science has an opportunity to contribute to a revived dialogue on the use of language in modern physics. Rhetoricians have only recently taken up the challenge of scientific communication as a research area. Indeed, perhaps the recent rise of our young field of study can be seen as a response to the persistent tension between modern science and the rhetorical means through which scientific arguments are invented and expressed. As researchers who are particularly interested in discourse, rhetoricians can offer great insight into how language is used in science. We are, however, at an infant stage in this pursuit, and there is a great amount of work yet to be done.

¹⁹ Weinberg, *Dreams of a Final Theory* 84-85.

²⁰ Bohm and Peat, *Science, Order, and Creativity* 84. See also, Pais, *Niels Bohr’s Times* 310.

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