# The Description and Explanation of Scientific Development in Thomas Kuhn's Philosophy of Science

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**Philosophy and Critical Thinking**

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**"I do hereby attest that I am the sole author of this thesis and that its contents are only the result of the readings and research I have done"**

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# Abstract

This thesis aims to explain Kuhn's description of scientific development as presented in his book *The Structure of Scientific Revolutions* by means of a precise definition of the concept of a paradigm. Central to Kuhn's description is the concept of a paradigm: normal science, scientific revolutions, and scientific communities are all defined in terms of paradigm. Therefore, in order to formulate that definition, a thorough and clear understanding of what precisely the term paradigm means is required. To that end, the thesis attempts to clarify the paradigm concept. It traces the development of the concept from its first appearance in Kuhn's writings, through the criticisms raised against its ambiguity, to its final development in terms of the two-sense distinction proposed by Kuhn. The study employs descriptive and analytic methods. The descriptive method is employed to represent Kuhn's initial account of scientific progress. The analytic method is employed to analyze the development of the concept of a paradigm.

# Introduction

The central task of the philosophy of science during the pre-1960s period was to determine what scientific rationality consists in and to articulate scientific methods. Philosophers of science, such as Rudolf Carnap, Imre Lakatos, Carl Hempel, and Karl Popper, believed that a scientific method has a normative function in that it tells scientists what they ought to do in theory-choice and theory-assessment situations so that they can appeal to rational procedures in their choice between competing theories.[1]

Rudolf Carnap's program of inductive logic is one attempt to describe a scientific method. In this method, hypotheses about the world that are found to be true most of the time are used to arrive at particular conclusions. The logical probability of the truth of these conclusions must then be established. For Carnap, the truth of scientific statements is probabilistic since it is based on facts obtained from experiments and observations. Thus, instead of establishing the truth of a conclusion starting from the truth of hypotheses, as in the case of deductive logic, Carnap's inductive logic aims to establish the logical probability of the truth of an inductive conclusion starting from observational evidences.[2]

Karl Popper proposed his method of falsificationism. Quite differently from Carnap's method, he argued that no rationally acceptable reasoning could establish the truth or the probability of truth of an inductive conclusion. Instead of verification, Popper claimed that falsification can provide science with rationality. A single piece of refuting evidence can be used to deductively establish the falsity of a hypothesis. A single black bird falsifies the hypothesis that all birds are white. That is, the method of falsificationism is built on the basis of the deductive validity of refutation. Thus, according to Popper, science proceeds in the following manner: first, scientists propose bold conjectures; then, they attempt to falsify, not verify, them. In this manner, some theories are weeded out from science, whereas others may continue to be employed by scientists until refuting evidence is discovered, at which point

1. Bird, A. Thomas Kuhn. Princeton: Princeton University Press. 2000, pp. 3-4.
2. Ibid., p. 4.

scientists will propose new conjectures and try to falsify them. Thus, science proceeds by a cycle of conjectures and refutations.[3]

The adherents to scientific methods believe that they can give an account that explains the development of science. Since the normative function of scientific methods enables scientists to follow rational procedures in their practice of science, then this normative function implies that science progresses toward the truth and that scientific knowledge accumulates. New theories are better than old theories in describing and explaining nature; and much more is currently known about the world than was known previously. This view is the traditional view of the history of science.[4]

However, both Carnap's and Popper's scientific methods are defective. On the one hand, Carnap's method is limited in scope and depends on the language which we choose to express the inductive hypotheses. Yet, the logical probability of the truth of these hypotheses should not depend on the choice of language if we want Carnap's method to be rational. On the other hand, Popper's method implies scepticism in science. That is, if we want to falsify a hypothesis, then we have to obtain a falsifying observation. However, since all observations are obtained using a theory and, according to Popper, the truth of a theory cannot be established, we can never know the truth of any observation. Thus, we cannot falsify a hypothesis because we do not know whether the falsifying observation is true.[5]

Moreover, some historical case studies reveal that the traditional view of the history of science does not fit the historical contexts of some scientific discoveries. For instance, one cannot say that Copernicus' theory simply provided more knowledge to those astronomers who worked on Ptolemy's theory. This is because the two theories are incompatible; the former claims that the Earth circles around the Sun, which moves through space, whereas the latter claims that the Earth is fixed at the center of the universe and that the Sun and other planets circle around the Earth. Thus scientific knowledge is not cumulative. Furthermore, some sociologists of science claim that in theory-choice and theory-assessment situations, scientists' decisions are

3. Ibid., pp. 4-5.
4. Horwich, P. World Changes: Thomas Kuhn and the Nature of Science. Cambridge, Massachusetts, and London: The MIT Press. 1993, p. 2.
5. Bird, Thomas Kuhn, op-cit., pp. 5-6.

not always based on rational grounds alone. Factors that are external to science, such as economic factors, the social relations between scientists, and even the nationality of the innovator, among others, play a significant role.[6]

The defects in the scientific methods of Carnap and Popper, together with the failure of the traditional view of the history of science to provide a correct image of scientific development, motivated Thomas Kuhn to develop his ideas in his book *The Structure of Scientific Revolutions*. According to Kuhn, scientific development cannot be explained in terms of a single universal scientific method and the description of scientific knowledge as cumulative is inaccurate. Kuhn wanted to establish a new image of scientific development. He claimed that "[h]istory, if viewed as a repository for more than anecdote or chronology, could produce a decisive transformation in the image of science by which we are now possessed."[7] The central argument of Kuhn's book is that to understand the development of science, one must describe and explain the process by which scientific knowledge is produced. That is, Kuhn claimed that the history of science exhibits a certain pattern of scientific development that can be described and explained in terms of the structure of the scientific community and the object to which the members of this community are committed, or what Kuhn called a "paradigm."[8] Therefore, what Kuhn proposed was a new view of science. A view that is concerned with the practices and processes that produce scientific knowledge instead of logically analyzing and explaining scientific knowledge as a finished product.

This thesis is divided into four chapters. In Chapter 1, I consider Kuhn's initial account of scientific development as presented in the first edition of his book *The Structure of Scientific Revolutions* and in papers composed around the same time. Central to this account is the concept of a paradigm. In Chapter 2, I discuss the main criticisms raised against Kuhn's initial account of scientific progress. The criticisms were mainly concerned with the ambiguity of the concept of a paradigm and with the irrationality and relativism implied by a paradigm shift. In Chapter 3, I discuss Kuhn's responses to his critics and the distinction that he makes between a paradigm in the sense of a disciplinary matrix and a paradigm in the sense of an exemplary problem

6. Ibid., pp. 6-8.
7. Kuhn, T. S. The Structure of Scientific Revolutions. 4th edition. Chicago and London: The University of Chicago Press. 2012, p. 1.
8. Ibid., p. 11.

solution. In Chapter 4, I provide an explanation of Kuhn's description of scientific development in terms of the precise definition of paradigms which I formulate in Chapter 3. The thesis ends with a summary of the main points considered in the study and a discussion of the conclusions at which I have arrived.

# Chapter 1

# Kuhn's Description of Scientific Development

In the Preface to his book *The Structure of Scientific Revolutions*, Kuhn tells us how he came to the concept of a paradigm. He claims that he discovered the concept of a paradigm when he was working at the Center for Advanced Studies in the Behavioral Sciences in 1958-1959. As an ex-physicist interacting with a community composed of social scientists, Kuhn was able to recognize the differences between the social sciences and the natural sciences. In the former, there is significant disagreement about the fundamentals of the field, whereas in the latter, there is a firm consensus on the fundamentals. He claims that "[a]ttempting to discover the source of that difference led [him] to recognize the role in scientific research of what [he has] since called 'paradigms'."[9] Here, Kuhn takes paradigms to be "universally recognized scientific achievements that for a time provide model problems and solutions to a community of practitioners."[10]

However, Kuhn did not confine his concept of a paradigm to this narrow definition. As he attempted to expound the pattern of the development of the natural sciences in his book *The Structure of Scientific Revolutions* and in the papers composed around the same time, the concept of a paradigm expanded equivocally. In this chapter, I discuss Kuhn's concept of a paradigm as it appeared in his papers *The Essential Tension: Tradition and Innovation in Scientific Research* and *The Function of Dogma in Scientific Research*. Then, I discuss his use of this concept in his book *The Structure of Scientific Revolutions*. These two papers together with his book form his initial theory of paradigm.

## 1.1 Convergent and divergent thinking in scientific research

Kuhn's paper *The Essential Tension: Tradition and Innovation in Scientific Research* was presented at the Third University of Utah Research Conference on the Identification of Creative Scientific Talent held in 1959.[11] The conference was concerned with identifying predictors of a creative personality to accelerate the progress and advancement of science. This is a dominant view of scientific progress

9. Ibid., p. xlii.
10. Ibid., p. xlii.
11. Kuhn, T. S. The Essential Tension: Tradition and Innovation in Scientific Research. In Kuhn TS (ed): The Essential Tension: Selected Studies in Scientific Tradition and Change. Chicago and London: The University of Chicago Press. 1959, p. 225.

in which science progresses through unrestricted imagination and divergent thinking. However, Kuhn emphasizes that this type of thinking is responsible for only some scientific progress. In contrast to the conference's concerns, he proposes that convergent thinking plays a fundamental role in scientific progress.

By divergent thinking, Kuhn means "the freedom to go off in different directions, rejecting the old solution and striking out in some new direction."[12] Practicing this type of thinking is appropriate in the periods of scientific revolutions, when novel solutions are required to replace the old solutions that failed to resolve the anomalies. On the other hand, convergent thinking is an "activity based firmly upon a settled consensus acquired from scientific education and reinforced by subsequent life in the profession."[13] Kuhn claims that scientists almost always practice this type of thinking in their research. It characterizes what he called normal research. Thus, we have "two complementary aspects of scientific advance."[14]

I think that Kuhn's training as a physicist enabled him to recognize the significant role played by the convergent type of thinking in the practice of science. Students of physical sciences are usually asked to tackle problems that have assured solutions and to produce solutions that fall within the expectations. Indeed, this is done only if the student adheres to the convergent type of thinking.

Kuhn introduces the term paradigm when he attempts to illustrate the role of convergent thinking in the progress of the natural sciences. To that end, he considers the educational system in such sciences. He notes that this education, in contrast to that in the social sciences, is conducted exclusively through textbooks. These books

> exhibit concrete problem solutions that the profession has come to accept as paradigms, and they then ask the student, either with a pencil and paper or in the laboratory, to solve for himself problems very closely related in both method and substance to those through which the textbook or the accompanying lecture has led him.[15]

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12. Ibid., p. 226.
13. Ibid., p. 227.
14. Ibid., p. 227.
15. Ibid., p. 229.

By solving problems that are very similar to the generally accepted paradigms, the student of the natural sciences is trained to be a convergent thinker.

Kuhn claims that the natural sciences have not always been characterized by a firm educational system conducted through generally accepted paradigms. Instead, each discipline has come to that status at some point in its history, which constitutes a discipline achieving a *first* consensus. The preconsensus phase, however, is characterized by the competition of different schools. Each school considers a particular range of phenomena and attempts to defend its special approach. As a result, this divergent practice of science did not produce rapid and systematic progress.[16]

Such rapid and systematic progress is characteristic of convergent or paradigm-based research. Kuhn notes the types of research problems undertaken by scientists of the mature sciences:

(i) bringing theoretical predictions and experimental results into closer agreement,

(ii) extending the scope of a theory to new phenomena, and

(iii) determining significant and concrete data.[17]

All scientists dedicate most of their professional lives to work of this sort. This work does not aim at novelty or innovation. Kuhn claims that "[u]nder normal conditions the research scientist is not an innovator but a solver of puzzles, and the puzzles upon which he concentrates are just those which he believes can be both stated and solved within the existing scientific tradition."[18]

We may well ask, if the educational system is characterized by a convergent type of thinking, then how can the practice of normal research be a source of novel ideas and revolutions? Kuhn thinks that no sort of work other than this tradition-bound work is so well suited to isolate and recognize anomalies that cause crises in science. In other words, normal research provides the background that enables scientists to

16. Ibid., pp. 230-232.
17. Marcum, J. A. Thomas Kuhn's Revolution: An Historical Philosophy of Science. London and New York: Continuum Press. 2005, pp. 46-47.
18. Kuhn, The Essential Tension, op-cit., p.234.

identify crisis-provoking anomalies: "In the mature sciences the prelude to much discovery and to all novel theory is not ignorance, but the recognition that something has gone wrong with existing knowledge and beliefs."[19] Therefore, the ultimate effect of normal research is invariably to change the tradition.

The essential tension in scientific research is that a scientist should adhere to the traditional work that is governed and guided by generally accepted paradigms but should be open-minded to recognize anomalies and be ready to abandon the tradition when an alternative that is capable of solving the anomalies is introduced. "[T]he productive scientist must be a traditionalist who enjoys playing intricate games by preestablished rules in order to be a successful innovator who discovers new rules and new pieces with which to play them."[20]

In conclusion, Kuhn, at this stage, defines paradigms as generally accepted concrete problem solutions that guide scientific education and scientific research. Students of the natural sciences are asked to solve problems that are similar and very closely related to those addressed within these paradigms. Scientists practice their normal research by stating and solving problems that are very closely related to those addressed by the generally accepted paradigms.

## 1.2 The dogmatism of science

Kuhn's paper *The Function of Dogma in Scientific Research* was presented at the Symposium on the History of Science at University of Oxford held in 1961. The paper starts by discussing the common view of scientists as characterized by open-mindedness and objectivity. However, Kuhn emphasizes that scientists typically know in advance the expected results of their investigations. If the results are not the expected ones, then scientists must attempt to bring observations into ever closer agreement with expectations. He claims that "[s]trongly held convictions that are prior to research often seem to be a precondition for success in the sciences."[21] This is what

19. Ibid., p. 235.
20. Ibid., p. 237.
21. Kuhn, T. S. The Function of Dogma in Scientific Research. In Crombie AC (ed): Scientific Change: Historical Studies in the Intellectual, Social and Technical Conditions for Scientific Discovery and Technical Invention from Antiquity to the Present. London: Heinemann. 1963, p. 349.

Kuhn means by the "dogmatism of mature science."[22] This dogmatism defines the problems that must be undertaken by scientists and determines the criteria for their solution.

In his paper *The Essential Tension*, Kuhn reserves the term 'paradigm' to refer to concrete problem solutions that are generally accepted by the scientific community.[23] However, in *The Function of Dogma in Scientific Research*, he uses an expanded notion of paradigm, which is enlarged to include the scientific classics that serve as models for scientific practice.[24] Examples of these classics are "Aristotle's *Physica*, Ptolemy's *Almagest*, Newton's *Principia* and *Opticks*, Franklin's *Electricity*, Lavoisier's *Chemistry*, and Lyell's *Geology*."[25] The expansion of the concept of a paradigm does not stop at this point. Kuhn next uses the term paradigm to include a generally accepted theory with exemplary problem solutions. In this sense, paradigm governs scientific research by determining the natural entities of the world, how these entities behave, what legitimate questions a scientist may ask, what methods and techniques may be used to handle these questions, and the nature of expected answers.[26] In other words, paradigms provide scientists with the maps needed to investigate the natural world.

Furthermore, the existence of a generally accepted paradigm is characteristic of a mature science. Scientists struggle to bring a paradigm into ever closer agreement with observations, extend it to areas to which it has not yet been applied, and articulate it by making it more precise in areas where the original formulation has been vague.[27] Work of this sort forms what Kuhn calls normal, or paradigm-based, research.[28] We encounter this notion of normal research in his paper *The Essential Tension*, and we encounter it again in his book *The Structure of Scientific Revolutions*.

However, paradigms cannot provide us with perfect maps. A breakdown in paradigms is inevitable. The anomalies that cause this breakdown ultimately lead to new discoveries. Kuhn claims that "[a]fter a first paradigm has been achieved, a

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22. Ibid., p. 349.
23. Kuhn, The Essential Tension, op-cit., p. 229.
24. Kuhn, The Function of Dogma in Scientific Research, op-cit., p. 352.
25. Ibid., p. 352.
26. Ibid., pp. 358-359.
27. Bird, Thomas Kuhn, op-cit., pp.33-34.
28. Kuhn, The Function of Dogma in Scientific Research, op-cit., p. 362.

breakdown in the rules of the pre-established game is the usual prelude to significant scientific innovation."[29] A crisis in a scientific discipline occurs when a number of serious anomalies accumulate. These anomalies resist persistent attempts at resolution. As a result, scientists begin to question the foundations of the paradigm of their discipline and conduct random experiments. Kuhn suggests that "[o]nly under circumstances like these . . . is a fundamental innovation in scientific theory both invented and accepted."[30]

We can take Kuhn's paper *The Function of Dogma in Scientific Research* as a fragment of the solution to problems concerned with the traditional image of scientific development. The more complete and articulated solution will be considered in his book.

## 1.3 The Structure of Scientific Revolutions

Kuhn's book *The Structure of Scientific Revolutions* contains 13 chapters. It can be divided into three parts: the first part covers chapters 1 through 5, in which Kuhn discusses the emergence of normal science from immature science; the second part covers chapters 6 through 8, in which he discusses the emergence of revolutionary science from normal science; and the third part covers chapters 9 through 13, in which he discusses the emergence of new normal science from revolutionary science.

The book was first published as a volume in the *Encyclopedia of Unified Science* in 1962. Space and time limits imposed by the editors forced Kuhn to write his book in the form of a short monograph. Thus, he did not have enough time to master and develop the philosophical ideas that are relevant to his account of scientific progress.[31] In the second edition of his book, published in 1970, Kuhn added a Postscript in which he responded to the criticisms that were raised against his initial account of scientific progress.

29. Ibid., p. 365.
30. Ibid., p. 367.
31. Grandy, R. E. Kuhn's World Changes. In Nickles T (ed): Thomas Kuhn. Cambridge: Cambridge University Press. 2003, p. 256.

### 1.3.1 Paradigms

In his book, Kuhn defines paradigms as concrete scientific achievements that share the following two characteristics:

(i) they are "sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity"[32]; and

(ii) they are "sufficiently open-ended to leave all sorts of problems for the redefined group of practitioners to resolve."[33]

In this sense, paradigms are "accepted examples of actual scientific practice—examples which include law, theory, application, and instrumentation."[34] These accepted examples provide the models that form a coherent tradition of scientific practice. Copernican astronomy, Aristotle's dynamics, Newton's mechanics, and the corpuscular theory of optics are all instances of coherent scientific traditions. The members of a scientific community are firmly committed to such traditions.[35]

Kuhn emphasizes that paradigms have priority over rules in guiding research: "[p]aradigms may be prior to, more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them."[36] He elsewhere defines rules as "operational definitions of scientific terms or else a set of necessary and sufficient conditions for the terms' applicability."[37] Professionally, scientists practice their research by modeling one problem solution on another. This is done by recognizing the resemblance between previous concrete achievements and new problems. Thus, paradigms, as concrete scientific achievements that share characteristics (i) and (ii), specify the criteria that determine both legitimate problems and legitimate solutions. In this manner, paradigms guide scientists in their research and prevent them from tackling insoluble problems. Pedagogically, students do not learn paradigms in the abstract. Instead, paradigms are learned through applications. The student is asked, either in the lecture or in the laboratory, to solve problems that

32. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 10.
33. Ibid., p. 11.
34. Ibid., p. 11.
35. Ibid., p. 11.
36. Ibid., p. 46.
37. Kuhn, T. S. Second Thoughts on Paradigms. In Kuhn TS (ed): The Essential Tension: Selected Studies in Scientific Tradition and Change. Chicago and London: The University of Chicago Press. 1974, p. 302.

are similar to what he has encountered in his textbook.[38] In this manner, the student is prepared to practice independent research in his future profession:

> As the student proceeds from his freshman course to and through his doctoral dissertation, the problems assigned to him become more complex and less completely precedented. But they continue to be closely modeled on previous achievements as are the problems that normally occupy him during his subsequent independent scientific career.[39]

When the scientist learns a paradigm he acquires theory, standards, and methods. The paradigm tells the scientist about the natural entities that populate the world and how these entities behave. Moreover, a paradigm enables the scientist to be unconcerned with the foundations of his scientific discipline. The scientist should concentrate on solving problems, and paradigms provide him with the criteria that determine soluble problems. In this manner, paradigms provide scientists with a map that guides a scientific community's research.[40]

### 1.3.2 Immature science

The image of scientific research as an activity of investigation guided and directed by a paradigm to which the members of a scientific community are firmly committed is not characteristic of science at all times. According to Kuhn, "[h]istory suggests that the road to a firm research consensus is extraordinarily arduous."[41] In the absence of a consensus on a paradigm, the fact-gathering activity becomes random and all facts seem to warrant investigation. Thus, there is little progress in scientific research.[42]

This situation is characteristic of the early stage of scientific development. It results in a number of competing schools. Each school has its special methods,

38. Kuhn, The Structure of Scientific Revolutions, op-cit., pp. 46-47.
39. Ibid., p. 47.
40. Marcum, Thomas Kuhn's Revolution, op-cit., p. 60.
41. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 15.
42. Ibid., p. 15.

standards, and a selected range of phenomena. Even when two schools consider the same phenomenon, they usually describe and interpret it in different ways. Therefore, in this situation, scientists do not share the same theoretical concepts or experimental techniques. The net result of these conditions is "something less than science."[43]

Kuhn calls this situation pre-paradigm (or immature) science. Scientific research in pre-paradigm science is not guided by a single paradigm. The period of immature science is initiated when some researchers have curiosity in a new field of nature or when they believe that a certain range of phenomena and some particular aspects of nature may warrant study.[44] Kuhn demonstrates the pre-paradigm situation with the discipline of physical optics before Newton.

> Being able to take no common body of belief for granted, each writer on physical optics felt forced to build his field anew from its foundations. In doing so, his choice of supporting observation and experiment was relatively free, for there was no standard set of methods or of phenomena that every optical writer felt forced to employ and explain. Under these circumstances, the dialogue of the resulting books was often directed as much to the members of other schools as it was to nature.[45]

This state of affairs does not continue forever. Scientists eventually commit to a single paradigm. When this new status is achieved, scientific research becomes a highly directed and progressive activity. Kuhn claims that "[w]hen the individual scientist can take a paradigm for granted, he need no longer, in his major works, attempt to build his field anew, starting from first principles and justifying the use of each concept introduced."[46]

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43. Ibid., p. 13.
44. Bird, Thomas Kuhn, op-cit., p. 32.
45. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 13.
46. Ibid., p. 20.

### 1.3.3 The emergence of normal science from immature science

According to Kuhn, the acquisition of a paradigm that permits a highly directed and esoteric type of research is a sign of maturity in the development of any scientific discipline. The transition of a scientific discipline to the status of maturity occurs when one of the pre-paradigm schools makes a splendid achievement that attracts the attention of the scientific community. The other schools, then, gradually disappear. Their disappearance is due to the conversion of their members to the new paradigm.[47] Kuhn asserts that "[t]he new paradigm implies a new and more rigid definition of the field. Those unwilling or unable to accommodate their work to it must proceed in isolation or attach themselves to some other group."[48]

The splendid scientific achievement that produces the first consensus must exhibit characteristics (i) and (ii) noted above. The scientific community's confidence in a paradigm is based on the ability of that paradigm to determine and solve problems in detail. Kuhn claims that "[p]aradigms gain their status because they are more successful than their competitors in solving a few problems that the group of practitioners has come to recognize as acute."[49]

When consensus is achieved, Kuhn calls the resulting status of scientific research normal science. It is "research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice."[50] Normal science is not directed to discover new kinds of phenomena or to invent new theories. Instead, it is restricted to articulating the phenomena and theories that are already involved in the paradigm. Thus, the range of phenomena and problems considered by normal science is relatively small and esoteric. However, Kuhn asserts that

> those restrictions, born from confidence in a paradigm, turn out to be essential to the development of science. By focusing attention upon a small range of relatively esoteric problems, the paradigm forces

47. Ibid., p. 19.
48. Ibid., p. 19.
49. Ibid., p. 24.
50. Ibid., p. 10.

> scientists to investigate some part of nature in a detail and depth that would otherwise be unimaginable.[51]

The commitment to a single paradigm by the members of a scientific community is thus necessary for the rapid and systematic progress of science.

At the time of its first appearance, a new paradigm solves only a few critical problems. However, it has potential success that is discoverable in selected examples. Practitioners of normal science are engaged in the actualization of this potential success. This actualization is "achieved by extending the knowledge of those facts that the paradigm displays as particularly revealing, by increasing the extent of the match between those facts and the paradigm's predictions, and by further articulation of the paradigm itself."[52] Thus, normal science involves somewhat routine activities that aim to force nature into the conceptual framework of the paradigm.

Normal science consists of experimental and theoretical investigations. Experimentally, the practitioners of normal science attempt to increase the reliability of their measurements and the precision of observations. Moreover, they strive to fill the gap between the predictions of theory and observational facts. They also attempt to increase the scope of the paradigm by considering phenomena that have not yet been investigated. To perform such work, a complex apparatus must be designed, constructed, and employed. Doing so requires considerable effort and ingenuity from scientists.[53]

In addition, normal scientists undertake theoretical problems. One of these problems is simply the use of existing theory to obtain theoretical predictions. Normal scientists also attempt to bring these theoretical predictions into closer agreement with observations. Furthermore, they extend the paradigm's scope by applying theory to new areas. Kuhn insists that "[t]hese three classes of problems—determination of

51. Ibid., p. 25.
52. Ibid., p. 24.
53. Marcum, Thomas Kuhn's Revolution, op-cit., p. 63.

significant fact, matching of facts with theory, and articulation of theory—exhaust . . . the literature of normal science."[54]

Kuhn addresses a question about the motivation of scientists for undertaking normal research: "if the aim of normal science is not major substantive novelties—if failure to come near the anticipated result is usually failure as a scientist—then why are these problems undertaken at all?"[55] Part of the answer is, of course, to obtain results that articulate the paradigm. However, this answer is not enough to account for the enthusiasm that scientists display for the somewhat routine work of normal research. According to Kuhn, what motivates scientists to undertake normal research problems is not the anticipated result or the intrinsic interest of the problem solutions but the intellectual challenge of how to achieve the solution.

> Bringing a normal research problem to a conclusion is achieving the anticipated in a new way, and it requires the solution of all sorts of complex instrumental, conceptual, and mathematical puzzles. The man who succeeds proves himself an expert puzzle-solver, and the challenge of the puzzle is an important part of what usually drives him on.[56]

Thus, normal science is not about testing the paradigm; instead, it is about solving puzzles. By puzzles, Kuhn means the "special category of problems that can serve to test ingenuity or skill in solution."[57] Puzzles involve both assured solutions and the rules that provide the steps by which these solutions are obtained. Kuhn employs the term 'rules' in a broad sense to indicate laws, theories, preconceptions, and viewpoints. Rules also involve methodological commitments, which determine the types of laws and explanations, and metaphysical commitments, which determine the natural entities that populate the world.[58]

54. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 34.
55. Ibid., p. 36.
56. Ibid., p. 36.
57. Ibid., p. 37.
58. Marcum, Thomas Kuhn's Revolution, op-cit., p. 64.

### 1.3.4 The emergence of revolutionary science from normal science

As observed above, normal scientific research does not aim to arrive at unexpected discoveries. However, violations of paradigm expectations occur from time to time during the period of normal science. Kuhn calls such violations anomalies, and they emerge from "the recognition that nature has somehow violated the paradigm-induced expectations that govern normal science."[59] He claims that scientific discoveries that are caused by anomalies are complex processes that involve both factual and theoretical novelties: "discovering a new sort of phenomenon is necessarily a complex event, one which involves recognizing both *that* something is and *what* it is."[60] Thus, a scientific discovery extends over a period of time, not always an extended period, to be conceptually assimilated. This assimilation requires a minor revision to the paradigm so that the new discovery falls within paradigm expectations.

However, not all anomalies lead to minor revisions to the paradigm. Some anomalies are more serious and raise doubts about the existing paradigm. Kuhn observes four types of serious anomalies:

(i) anomalies that are in direct conflict with an essential law of nature,

(ii) anomalies that prevent an important application of theory,

(iii) anomalies that stem from a development in normal research, and

(iv) anomalies that cannot be resolved despite repeated attempts at resolution.[61]

The accumulation of such anomalies generates "a period of pronounced professional insecurity"[62] which Kuhn calls a crisis. This insecurity is the consequence of the inability of the existing paradigm to solve the persistent anomalies. The scientific community then begins to raise doubts about the procedures and techniques of the existing paradigm and about the reliability of its past achievements. Therefore, many

59. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 53.
60. Ibid., p. 55.
61. Bird, Thomas Kuhn, op-cit., pp. 43-44.
62. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 68.

novel theories are invented by members of the scientific community to resolve the anomalies. The situation, thus, becomes similar to that in the pre-paradigm period.[63]

Kuhn emphasizes that the initial response of the scientific community to crisis is not rejection of the existing paradigm. Instead, scientists attempt to make several articulations and modifications to the existing paradigm to resolve the anomalies. The scientific community cannot reject the existing paradigm unless there is an alternative candidate. That is, the rejection of a paradigm without a substitute is a rejection of science itself.[64] Kuhn claims that "[o]nce it has achieved the status of paradigm, a scientific theory is declared invalid only if an alternate candidate is available to take its place."[65]

According to Kuhn, a crisis in a scientific discipline ends in one of the following three possible ways:

(i) The existing paradigm may be capable to resolve the persistent anomalies; hence, normal science practice is restored.

(ii) The anomalies cannot be resolved by minor revisions or modifications to the existing paradigm. In this case, the scientific community identifies and tables the anomalies for future analysis and investigation.

(iii) The anomalies are resolved with the replacement of the existing paradigm by a new one.[66]

Kuhn rejects Popper's falsificationism because the decision to abandon one paradigm must simultaneously be the decision to accept another and this decision involves not only the comparison of both paradigms with nature but also the comparison of the paradigms with each other. "No process yet disclosed by the historical study of scientific development at all resembles the methodological stereotype of falsification by direct comparison with nature."[67] Furthermore, Kuhn rejects Popper's principle because the falsifying evidence or anomalies may be

63. Marcum, Thomas Kuhn's Revolution, op-cit., p. 65.
64. Kuhn, The Structure of Scientific Revolutions, op-cit., pp. 78-79.
65. Ibid., p. 77.
66. Ibid., pp. 81-82.
67. Ibid., p. 77.

resolved, after many attempts, within the existing paradigm and thus turn out to be mere puzzles of normal science.[68] I discuss Kuhn's view of Popper's method of falsification in more detail in Chapter 2.

During the period of crisis, scientists do not practice normal science; instead, they practice what Kuhn calls extraordinary science. Practitioners of extraordinary science undertake random experiments, suggest speculative theories, analyze the basic assumptions of the existing paradigm, and examine the philosophical foundations of their field. They do so to replace the existing paradigm with a new paradigm that is capable of resolving the crisis-provoking anomalies.[69] Thus, whereas normal science is cumulative, extraordinary science is not; instead, "it is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications."[70]

Kuhn calls the irreversible change from extraordinary science to a new normal science a scientific revolution. He defines scientific revolutions as "non-cumulative developmental episodes in which an older paradigm is replaced in whole or in part by an incompatible new one."[71] Moreover, Kuhn insists that the old theory cannot simply be considered a special case of the new theory, under certain conditions. In other words, the old theory cannot be derived from the new theory. This radical difference between the old and new theories forms the basis for Kuhn's incommensurability thesis. He observes three kinds of incommensurability. First, the proponents of competing paradigms disagree about the legitimate problems to be solved and the standards to be applied to their solutions. Thus, problems whose solutions were important to the older paradigm may be neglected or considered unscientific, and questions that did not exist in the older paradigm may acquire great importance in the new paradigm. Second, a paradigm shift produces a conceptual shift that inhibits direct comparison between the old and new paradigms. The theoretical expressions in the two paradigms do not have the same meanings and references. Hoyningen-Huene observes that Kuhn's notion of conceptual shift has an extensional aspect and an intensional aspect. The extensional aspect of a conceptual shift consists of the

68. Marcum, Thomas Kuhn's Revolution, op-cit., p. 66.
69. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 87.
70. Ibid., p. 85.
71. Ibid., p. 92.

transition of certain objects from the extension of one concept to the extension of another. An example for this extensional change is the change in the concept of a planet. In Ptolemaic astronomy, the sun and moon are considered to be planets, whereas in Copernican astronomy, they cease to be considered such. The intensional aspect of a conceptual shift consists of a change in the attributes of objects that fall under the concept. For example, Newton's concept of mass as a conserved quantity is different from Einstein's concept, where mass can be transformed into energy. Third, paradigm changes cause changes in world view. That which is a swinging object in the world of Galileo is a constrained falling object in the world of Aristotle.[72]

Because of the incommensurability of competing paradigms, the resolution of scientific revolutions is not a straightforward process. The proponents of competing paradigms disagree on the relevant proof and evidence. Kuhn claims that "The competition between paradigms is not the sort of battle that can be resolved by proofs."[73] Moreover, communication among the proponents of competing paradigms is only partial. The theoretical expressions and concepts that are employed in different paradigms have different meanings and uses.[74] These difficulties in resolving scientific revolutions motivate Kuhn to search for an answer for the following question: why does one adopt a new paradigm and reject the old paradigm? Put differently, how does one group in the scientific community persuade another to change paradigms?

Kuhn notes several reasons that motivate the members of a scientific community to adopt the new paradigm. Of course, the most obvious reason is the ability of the new paradigm to solve the crisis-provoking anomalies. Other reasons include successful predictions of new phenomena and an impressive quantitative fit between the theoretical predictions and observations made by the new paradigm. Kuhn insists that such reasons are not compelling, i.e., they cannot act as a logical proof.[75] In addition, Kuhn notes some reasons that are external to science. These reasons include economic

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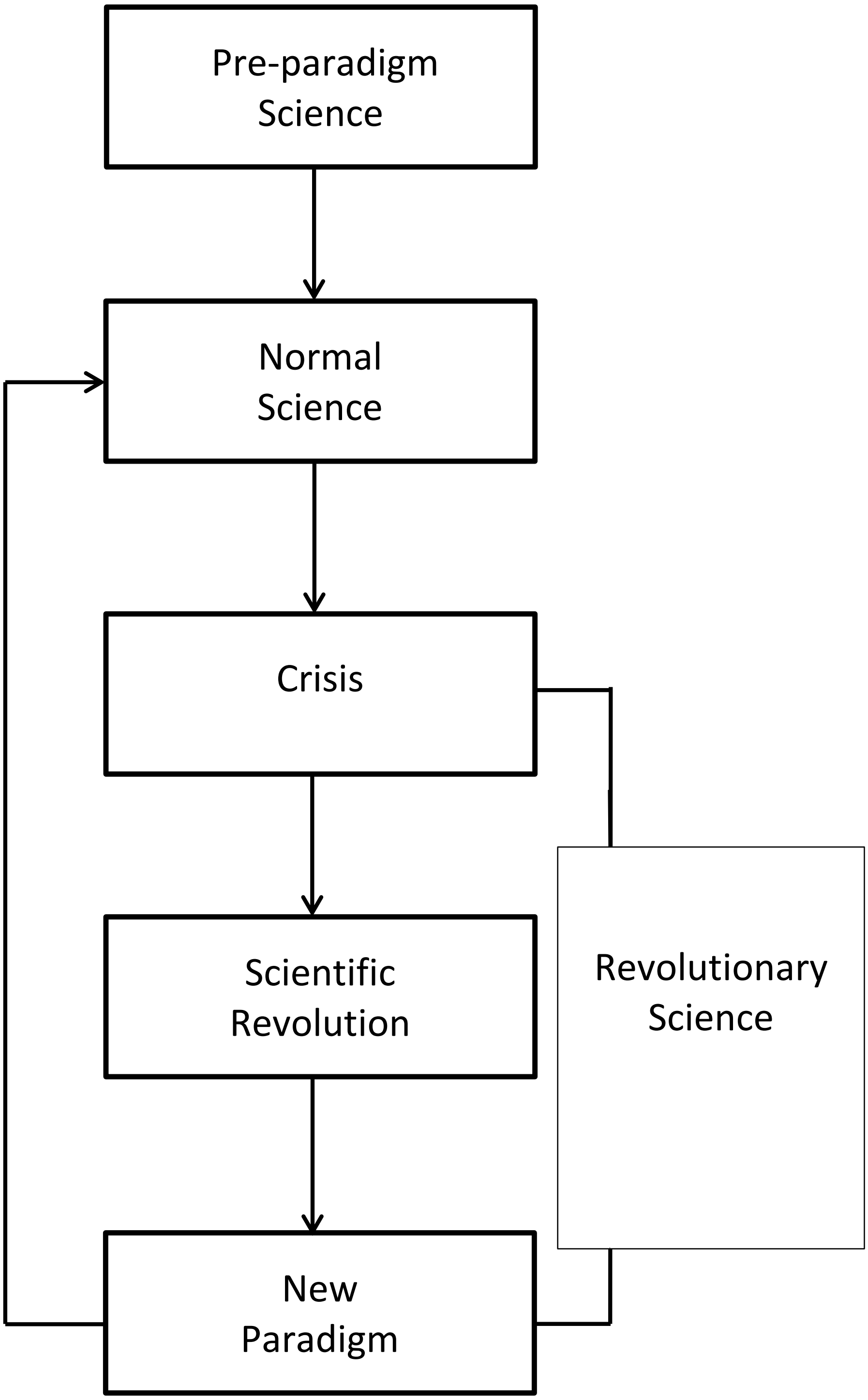
72. Hoyningen-Huene, P. Reconstructing Scientific Revolutions: Thomas S. Kuhn's Philosophy of Science. Translated by Alexander T. Levine. Chicago and London: The University of Chicago Press. 1993, pp. 208-212.
73. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 147.
74. Ibid., p. 148.
75. Ibid., pp. 153-154.

and political considerations, national sentiment, and the personality and reputation of the innovator.[76]

When the majority of the members of a scientific community convert to the new paradigm, a new period of normal science commences. At this point, the circular pattern of Kuhn's image of scientific development becomes clear. The period of pre-paradigm science ends when a candidate paradigm, by making a significant and unprecedented achievement, attracts the majority of scientists away from other competing paradigms. Then, a period of normal science, which is characterized by a firm commitment to a single paradigm that guides and directs the scientific research, begins. Since no theory is absolutely perfect, a number of serious anomalies will ultimately arise and make the practitioners of normal science question the fundamental hypotheses of the existing paradigm and the foundations of their discipline. As a result, a crisis occurs in science. During the period of crisis, scientists practice extraordinary science, which is characterized by the invention of a number of candidate theories to solve the crisis-provoking anomalies. The crisis culminates in a scientific revolution when the majority of the scientific community's members agree to commit to one of the competing paradigms. With this general agreement, a new period of normal science begins. The development of a scientific discipline circulates in this manner. The figure below demonstrates the circular pattern of Kuhn's image of scientific development:

76. Bird, Thomas Kuhn, op-cit., p. 48.


Pre-paradigm Science
Normal Science
Crisis
Scientific Revolution
New Paradigm
Revolutionary Science

Thus, according to Kuhn, science progresses through revolutions. However, we must distinguish between this progress and that which occurs during the period of normal science. Progress in normal science is cumulative in the sense that the solutions to puzzles increase our knowledge and information about the natural world. Kuhn claims that "[i]n its normal state, then, a scientific community is an immensely efficient instrument for solving the problems or puzzles that its paradigms define. Furthermore, the result of solving those problems must inevitably be progress."[77] Revolutionary progress is, in contrast, non-cumulative because of the incommensurability of the pre- and post-revolutionary paradigms. This progress involves successful solutions to the crisis-provoking anomalies that the previous paradigm could not solve, the ability to solve additional problems with high precision and detail, and a refined and better understanding of the natural world. Kuhn describes revolutionary progress as "a process of evolution *from* primitive beginnings."[78] Thus, for Kuhn, the progress of science through revolutions is not directed toward some final truth. He claims that "[w]e may . . . have to relinquish the notion, explicit or implicit, that changes of paradigm carry scientists and those who learn from them closer and closer to the truth."[79]

I believe that the power of Kuhn's argument relies on the fact that he appealed to historical case studies, i.e., to the actual behavior of scientists in their practice of science. He clearly referred to and discussed a number of historical cases including the development of the Copernican astronomical system, Darwin's proposition of the evolution theory, the emergence of Newtonian mechanics, Lavoisier's invention of the oxygen theory of combustion, Einstein's formulation of the theory of special relativity, among others. Moreover, before publishing his book *The Structure of Scientific Revolutions*, Kuhn has already authored a book entitled *The Copernican Revolution* in which he studied in depth and detail the historical context of the transition from the traditional Neoplatonic astronomy to the new astronomy of Copernicus.

77. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 165.
78. Ibid., p. 169.
79. Ibid., p. 169.

# Chapter 2

# Criticisms against Kuhn's Description of Scientific Development

*The Structure of Scientific Revolutions* was widely read by scholars from various disciplines. Some reactions were congenial, but others were critical. Many critics found that Kuhn's concept of paradigm involves serious ambiguity. Others criticized him because his new image of scientific development implies irrationality and relativism in science. Some philosophers of science, most notably Popper and Lakatos, recognized that Kuhn's views are in direct conflict with their philosophical positions.

In this chapter, I consider some critical reviews and then consider the critiques presented in the symposium *Criticism and the Growth of Knowledge* held in London in 1965. In this symposium, Kuhn and Popper, the two most influential philosophers of science of the twentieth century, discussed and compared their ideas concerning the nature of scientific development.

## 2.1 Critical Reviews

Many critical reviews of *The Structure of Scientific Revolutions* have appeared since 1964. Some of these reviews have been published in professional philosophy journals and others have been included as sections or chapters in books concerned with Kuhn's philosophy of science. One notable review is that by Dudley Shapere. Shapere acknowledges that Kuhn is convincing in his attempt to attack the prevailing image of scientific progress as an accumulative process. However, he is concerned with certain problems that are associated with Kuhn's new image of science, especially the problem of relativism that stems from the notions of paradigm shift and incommensurability.

Shapere examines Kuhn's notion of a paradigm, and he points to several problems that are associated with it. First, the notion is ambiguous. He notes that Kuhn uses the term 'paradigm' in several different senses. Sometimes, paradigms are accepted examples of actual scientific practice; at other times, they are strong networks of conceptual, theoretical, instrumental, metaphysical, and methodological commitments. He also notes that Kuhn uses the term 'paradigm' to refer to certain patterns that guide us in modeling our theories; elsewhere, paradigms seem to be theories that are to be articulated.[80] Therefore, Shapere concludes that

> The term 'paradigm' thus covers a range of factors in scientific development including or somehow involving laws and theories, models, standards, and methods (both theoretical and instrumental), vague intuitions, explicit or implicit metaphysical beliefs (or prejudices). In short, anything that allows science to accomplish anything can be a part of (or somehow involved in) a paradigm.[81]

Shapere is also confused over the difficulty that although paradigms, in Kuhn's view, cannot be described adequately in words, they can be recognized by historians of science by direct inspection.[82] For Kuhn, historians of science can "agree in their *identification* of a paradigm without agreeing on, or even attempting to produce, a full *interpretation* or *rationalization* of it."[83] Shapere argues that in most of the historical cases that Kuhn discusses, it is the theory, rather than the paradigm, that poses problems for scientists to solve, provides standards for judging legitimate solutions, supplies researchers with criteria for the selection of data, and so on. Shapere claimed that Kuhn appeals to theory because "it is as near as he can get in words to the inexpressible paradigm."[84]

Shapere also considers the distinction between paradigms and different articulations of a single paradigm. Newton, Lagrange, Hamilton, Hertz, and Mach invented different formulations of classical mechanics; and these formulations involve different commitments, for instance, to forces, to energy, or to variational principles. Thus, can we say that the adherents to different formulations of classical mechanics are adherents to different paradigms? For Shapere, the distinction between paradigms and different articulations of a single paradigm, and between normal science and revolutionary science, is a matter of degree. He claims that the existence of competing

80. Shapere, D. (1964). The Structure of Scientific Revolutions. In Shapere D (ed): Reason and the Search for Knowledge: Investigations in the Philosophy of Science. Dordrecht: D. Reidel Publishing Company. 1964, p. 39.
81. Ibid., p. 39.
82. Ibid., p. 40.
83. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 44.
84. Shapere, The Structure of Scientific Revolutions, op-cit., p. 41.

articulations and debate over fundamentals occur throughout the development of any scientific discipline; and there are some guiding factors that are common between different traditions.[85]

Furthermore, he notes that the reasons that Kuhn discusses for supposing the existence of paradigms, such as the inability to determine accurate methodological rules and the observation that similar theories may be considered to be diverse incomplete expressions of a common paradigm and from which they are abstracted, are unconvincing. According to Shapere, such reasons

> do not compel us to adopt a mystique regarding a single paradigm which guides procedures, any more than our inability to give a single, simple definition of 'game' means that we must have a unitary but inexpressible idea from which all our diverse uses of 'game' are abstracted.[86]

Shapere then considers a problem that is associated with Kuhn's notion of paradigm shift. In *The Structure of Scientific Revolutions* Kuhn argues that a fundamental change in the meaning of a term occurs after a scientific revolution. For example, the meaning of the term 'mass' in Newton's physics has changed in Einstein's; thus, the former cannot be derived from the latter under certain conditions.[87] Shapere argues that instead of Kuhn's argument, one may well say that the application of a term has changed after a paradigm shift but its meaning has remained the same.[88] In this manner, Shapere saves the derivability of earlier sciences from later sciences. He believes that Kuhn fails to notice this distinction. This problem led him to criticize Kuhn's notion of incommensurability. Shapere argued that

> if the differences between successive paradigms are both necessary and irreconcilable, and if those differences consist in the paradigms' being incommensurable—if they disagree as to what the facts are, and even as to the real problems to be faced and the standards which a

85. Ibid., p. 42.
86. Ibid., pp. 42-43.
87. Kuhn, The Structure of Scientific Revolutions, op-cit., pp. 101-102.
88. Shapere, The Structure of Scientific Revolutions, op-cit., p. 44.

> successful theory must meet—then what are the two paradigms disagreeing about? And why does one win?[89]

Thus, Shapere claimed that incommensurability entails incomparability between successive paradigms and reduces the progress in science to mere change. That is, one cannot assess successive incommensurable paradigms according to their efficacy to solve the same problems, or meet the same criteria, or deal with the same facts.

Finally, Shapere accuses Kuhn of relativism. That is, in his book, Kuhn tells us that a new paradigm often leads to a redefinition of the corresponding science and that adherents to different paradigms are at cross-purposes and see different things when they look at the same phenomenon.[90] Moreover, Shapere claimed that "Kuhn has already told us that the decision of a scientific group to adopt a new paradigm is not based on good reasons; on the contrary, what counts as a good reason is determined by the decision."[91]

Another critic, Ernan McMullin, claimed that Kuhn's account of paradigm change undermines the rationality of science. He called attention to Kuhn's use of the metaphors of the gestalt switch and conversion and to Kuhn's claim that adherents to competing paradigms often fail to make full contact with each other's perspectives. He also argued that irrationality is involved in Kuhn's treatment of theory-choice situations because Kuhn emphasizes that factors such as the idiosyncrasies of the individual scientist, philosophical views, and personality differences play a role in such situations.[92] Moreover, irrationality is involved in the circular role played by paradigms in theory-choice situations because "the evaluative procedures depend on the paradigm, and the paradigm itself is in question, [thus] there can be no agreed-upon way to adjudicate the choice between rival paradigms."[93] Thus, what prevents competing scientific groups from agreement on which paradigm is the better is the fact that the standards in terms of which the debate can be resolved are themselves part of

89. Ibid., p. 45.
90. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 149.
91. Shapere, The Structure of Scientific Revolutions, op-cit., p. 47.
92. McMullin, E. Rationality and Paradigm Change in Science. In Horwich P (ed): World Changes: Thomas Kuhn and the Nature of Science. Cambridge, Massachusetts, and London: The MIT Press. 1993, p. 55.
93. Ibid., p. 58.

the paradigm; hence, there are no neutral standards, or at least not enough, to reach on an agreement.

Alexander Bird raised two criticisms against Kuhn's description of scientific progress. The first is concerned with the normal science-revolutionary science dichotomy. Bird suggested that there may be no sharp distinction between normal and revolutionary science. Instead, he proposed a continuum of changes from small cumulative additions through moderate revisions to revolutionary changes. He noted that one can classify the degree of paradigm change by introducing two parameters. The first is the cause of the paradigm change, which includes a non-anomalous puzzle, a minor anomaly, and a serious anomaly. The second is the result of this change, which includes cumulative addition, minor paradigm revision, and major paradigm revision. Normal and revolutionary sciences can be defined in terms of these two parameters. According to Kuhn's description of scientific progress, one may conclude that the causes of change in normal science are non-anomalous puzzles and minor anomalies and that the result of change is cumulative additions. Additionally, in the case of revolutionary science, the cause of change is serious anomalies, and the result of change is major paradigm revisions. Bird argued that this simple dichotomy does not cover all cases of scientific progress. For example, a minor anomaly can lead to a minor paradigm revision, as in the case of the discovery of X-rays, or it can lead to a major paradigm revision, as in the case of Hubble's discovery of the expanding universe. Other historical cases may correspond to several other combinations of causes and results of paradigm change that do not fit Kuhn's simple dichotomy. Thus, one could expect paradigm changes of various intervening degrees of magnitude.[94]

Bird's second criticism is that Kuhn's image of scientific development is inadequate to account for some classes of scientific discovery. In Kuhn's view, a paradigm change is either small and cumulative (normal-scientific change) or a large change that implies revision or rejection of the existing paradigm (revolutionary change). Furthermore, all scientific revolutions must come after a crisis. Bird, however, claimed the existence of large changes that are not revisionary and of scientific revolutions that are not preceded by crises.[95]

94. Bird, Thomas Kuhn, op-cit., pp. 50-54.
95. Ibid., p. 50.

If there are conservative scientific revolutions that are not revisionary and not accompanied by the rejection of a paradigm, then Kuhn's image of scientific progress is defective. That is, revolutionary science would be cumulative just like normal science. It seems that this is the reason why Kuhn denies the existence of non-revisionary scientific revolutions:

> After the pre-paradigm period the assimilation of all new theories and of almost all new sorts of phenomena has in fact demanded the destruction of a prior paradigm and a consequent conflict between competing schools of scientific thought. Cumulative acquisition of unanticipated novelties proves to be an almost non-existent exception to the rule of scientific development.[96]

Kuhn's view here seems to suggest that the existing paradigm constitutes a complete picture of the world. Thus, any phenomenon is either within the existing paradigm or in conflict with it. According to Kuhn, "[t]he commitments that govern normal science specify not only what sorts of entities the universe does contain, but also, by implication, those that it does not."[97] In other words, anything is either predicted or excluded. Therefore, if paradigms are not complete, then we could discover a phenomenon of great significance that is not in conflict with the existing paradigm and does not require a revision. This phenomenon would be neither predicted nor excluded. Bird called it an unnoticed phenomenon.[98] Since unnoticed phenomena are not anomalous, Bird claimed that some of them may lead to important discoveries that produce conservative, non-revisionary scientific revolutions.

Bird mentioned the discovery of the structure of DNA as an example of a conservative scientific revolution. The problem was well articulated and the range of possible solutions was loosely restricted. The discovery of the helical structure of DNA containing base pairings was unexpected but not in contradiction with the

96. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 96.
97. Ibid., p. 7.
98. Bird, Thomas Kuhn, op-cit., p. 60.

expected results. This discovery caused a revolution in molecular genetics and biochemistry, but it did not involve revisions to the existing paradigm.[99]

Bird also called attention to the existence of scientific revolutions that are not preceded by crises. Einstein's theory of general relativity provides an instance of such revolutions. Unlike the theory of special relativity, it was not invented as a solution to persistent serious anomalies. Instead, what motivated Einstein to invent general relativity was his own genius to connect certain phenomena that others could not see any connection between them, for example, the connection between the experience of accelerated motion and that of being under the influence of gravity.[100]

It seems that Kuhn's constraint that scientific revolutions must be revisionary and preceded by crises is due to his focusing on a small number of revolutions such as Newton's mechanics, Einstein's theory of special relativity, Lavoisier's oxygen theory of combustion, and Darwin's theory of evolution. He does not consider other scientific revolutions that are non-revisionary, such as the discovery of the structure of DNA, or those that emerged without crises, such as Einstein's theory of general relativity.

### 2.2 London Colloquium: The Growth of Scientific Knowledge

In the Colloquium *Criticism and the Growth of Knowledge*, Kuhn delivered a paper in which he compared his views concerning the growth of scientific knowledge to those of Popper. Kuhn's paper was followed by lively discussion and critical papers delivered by Karl Popper, Imre Lakatos, John Watkins, Stephen Toulmin, Paul Feyerabend and Margaret Masterman. The criticisms were mainly concerned with Kuhn's notions of paradigm and normal science. Some critics leveled the accusation that his account of scientific development implies irrationality and relativism in science.

99. Ibid., p. 60.
100. Ibid., p.58.

### 2.2.1 Logic or psychology?

Kuhn begins his paper *Logic of Discovery or Psychology of Research?* by focusing on the similarities between his view and that of Popper. Both views are concerned with the dynamic process by which scientific communities produce knowledge rather than with the final structure of their products. Both views appeal to historical cases and to the actual scientific life of scientists. Moreover, both views emphasize the revolutionary character of scientific progress in which an old theory is replaced by a new theory.[101] However, there are sharp differences between the two views that Kuhn likens to a gestalt switch: "Sir Karl and I do appeal to the same data; to an uncommon extent we are seeing the same lines on the same paper… . Though the lines are the same, the figures which emerge from them are not."[102] Kuhn attempts to make Popper see what he sees when both examine the same cases in the history of science. "How am I," asked Kuhn, "to show him what it would be like to wear my spectacles when he has already learned to look at everything I can point to through his own?"[103] To help Popper in the gestalt switch, Kuhn identified and treated three Popperian locutions:

(i) theory testing,

(ii) learning from our mistakes, and

(iii) falsification.[104]

Popper's view of the role of theory tests is articulated in his book *Conjectures and Refutations*, in which he briefly characterized his view in the form of several propositions. I consider here the relevant propositions:

(i) A theory that is not refutable is not scientific.

(ii) The aim of a genuine test is to falsify a theory.

101. Kuhn, T. S. Logic of Discovery or Psychology of Research?. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, pp. 1-2.
102. Ibid., p. 3.
103. Ibid., p. 3.
104. Marcum, Thomas Kuhn's Revolution, op-cit., pp. 84-85.

(iii) When a testable theory is falsified, some of its proponents may still adhere to it. For example, they may introduce *ad hoc* assumptions or re-interpret the theory. However, such procedures may destroy or lower the scientific status of the theory.[105]

Thus, according to Popper's view, theory testing aims to refute the theory. Kuhn tackled this Popperian locution by claiming that there is only one sense in which tests regularly enter science. This is within the practice of normal science. During normal science, scientists do not conduct tests to assess the correctness of a theory; instead, the basic theory is taken for granted, and tests are conducted to determine the skill and ingenuity of a scientist as a puzzle solver. Thus, what can be tested are "statements of an individual's best guesses about the proper way to connect his own research problem with the corpus of accepted scientific knowledge."[106] In other words, the aim of experiments and measurements in the normal practice of science is to explicitly demonstrate the implicit agreement between the existing paradigm and the world.[107] Kuhn recognized that Popper's view of theory testing is, contrary to Popper's claims, appropriate only in rare situations of scientific revolutions. He suggested that "Sir Karl has characterized the entire scientific enterprise in terms that apply only to its occasional revolutionary parts."[108] However, I think that Kuhn seems to be unconscious of the change that he has made to his view when he proposed this last suggestion. In his book *The Structure of Scientific Revolutions*, he claimed that a negative experimental result cannot refute a theory, even in periods of revolutionary science. The negative result, in this case, would suggest a disproof that compels scientists to reject the theory, a view that Kuhn explicitly refused in his book. Thus, if Kuhn must make a suggestion that is consistent with his previous views, then he must suggest that Popper's view of theory testing is not appropriate in either normal or revolutionary science.

105. Popper, K. Conjectures and Refutations: Growth of Scientific Knowledge. London: Routledge. 1963, pp. 36-37.
106. Kuhn, Logic of Discovery or Psychology of Research?, op-cit., p. 4.
107. Kuhn, T. S. The Function of Measurement in Modern Physical Science. In Kuhn TS (ed): The Essential Tension: Selected Studies in Scientific Tradition and Change. Chicago and London: The University of Chicago Press. 1961, p. 192.
108. Kuhn, Logic of Discovery or Psychology of Research?, op-cit., p. 6.

Kuhn argued that Popper's misconception of the important role of normal science led him to propose an incorrect demarcation between science and nonscience. According to proposition (i) above, Popper's demarcation criterion is the potential refutability of theories. Thus, in Popper's view, astrology is not a science because it is not refutable. However, Kuhn disagreed with Popper on this point. Kuhn claimed that astrology failed to be a science because it failed to develop a puzzle-solving tradition that is characteristic of paradigmatic normal science. "To rely on testing as the mark of a science is to miss what scientists mostly do and, with it, the most characteristic feature of their enterprise."[109]

The second Popperian locution Kuhn tackled is learning from our mistakes, or what Popper referred to as 'conjecture and refutation.' According to Kuhn, the mistakes to which Popper referred to are out-of-date scientific theories. Thus, for Popper, Ptolemaic astronomy, the phlogiston theory, and Newtonian mechanics are mistakes and to learn from our mistakes is to reject one of these theories and replace it with another, i.e., to reject the old paradigm and to replace it with a new paradigm. Contrary to Popper, Kuhn insisted that what should be considered mistakes are those made by scientists during their practice of normal science. These mistakes involve an individual's failure to obey one or more of the pre-established paradigmatic rules. For example, an individual scientist may make mistakes in observations, calculations, or data analysis. Such mistakes can be isolated and corrected without the need to replace the entire paradigm. Popper's sense of mistake, however, affects the entire paradigm and requires the rejection and replacement of the entire paradigm.[110] Kuhn claimed that Popper has confused normal with revolutionary science: "[l]ike the term 'testing', 'mistake' has been borrowed from normal science, where its use is reasonably clear, and applied to revolutionary episodes, where its application is at best problematic."[111]

Kuhn then tackled the third Popperian locution, falsification. According to proposition (iii) above, Popper acknowledged that it is always possible to defend a theory against falsification by introducing *ad hoc* assumptions or by questioning the data. However, he claimed that such procedures are possible only at the expense of destroying or lowering the scientific status of the theory. Kuhn agreed with Popper

109. Ibid., p. 10.
110. Ibid., pp. 11-12.
111. Ibid., p. 12.

that a theory can be modified in several ways by *ad hoc* adjustments, but contrary to Popper, such procedures do not negatively affect scientific theories; instead, "it is often by challenging observations or adjusting theories that scientific knowledge grows."[112]

Kuhn also considered the common view that scientists approach closer to the truth when they make new discoveries and invent new theories. He denied this view of scientific progress; instead, he claimed that with the passage of time the progress of science can be seen in the fact that new theories are more and more articulated, and they are matched to nature at an increasing number of points with more precision. In the process, the number of subject matters to which the normal-science research can be applied and the number of scientific specialties increase with time.[113]

### 2.2.2 Critiques

Popper admitted that he did not recognize the distinction between normal and revolutionary science. He is indebted to Kuhn for "opening [his] eyes to a host of problems which previously [he] had not seen quite clearly."[114] Popper now admitted the existence of normal science. However, he criticized the paradigmatic activities of normal science:

> Normal science, in Kuhn's sense, exists. It is the activity of the non-revolutionary, or more precisely, the not-too-critical professional, of the science student who accepts the ruling dogma of the day; who does not wish to challenge it; and who accepts a new revolutionary theory only if almost everybody else is ready to accept it–if it becomes fashionable by a kind of bandwagon effect.[115]

Popper regarded normal science as a danger and a threat to science. The normal scientist, in Popper's view, is a victim of the educational system. He has been taught

112. Ibid., p. 13.
113. Ibid., p. 20.
114. Popper, K. Normal Science and its Dangers. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 52.
115. Ibid., p. 52.

badly, in a dogmatic manner. He is taught to apply certain techniques to routine problems without asking for the reason for such application. He thus becomes an applied scientist. His success, as a normal scientist, depends on his ability to demonstrate that the generally accepted paradigm can be appropriately applied to certain routine problems or to what Kuhn calls puzzles.[116]

Moreover, Popper argued that many cases in the history of science do not fit Kuhn's image of scientific development, in which a scientific discipline, normally, is dominated by a single paradigm and is developed through a sequence of dominant paradigms, with intervening scientific revolutions. For example, descriptive botanists were regularly faced with genuine problems such as problems of distribution, species differentiation, characteristic enemies, and characteristic plant diseases, among others. These problems forced botanists to adopt an experimental approach, instead of the descriptive approach, which led to plant physiology, which in turn led to the combined theoretical and experimental science of botany. These different stages occurred almost without any perception of revolutions, and at each stage, there were many genuine problems rather than routine puzzles. Another example is the theory of matter. There are three dominant physical theories concerning the structure of matter: the continuum theory, the atomic theory, and theories that attempt to combine the two. Regular and fruitful discussions between the proponents of these theories have been ongoing since antiquity.[117] To these two historical cases noted by Popper, we can add Bird's two cases of the discovery of the structure of DNA and Einstein's theory of general relativity, discussed above. Thus, we have four historical cases that do not fit Kuhn's image of scientific progress.

Although Popper claimed that science is essentially critical and consists of bold conjectures that are subject to criticism, he insisted on the important role played by dogmatism in science. That is, "[i]f we give in to criticism too easily, we shall never find out where the real power of our theories lies."[118]

I think that Popper's last position is inconsistent with his early view. Dogmatism may involve adherence to a theory despite the falsifying results, either by introducing *ad hoc* assumptions or by re-interpreting the theory. However, according to

116. Marcum, Thomas Kuhn's Revolution, op-cit., p. 87.
117. Popper, Normal Science and its Dangers, op-cit., pp. 54-55.
118. Ibid., p. 55.

proposition (iii) above, Popper claimed that such dogmatic procedures may destroy or lower the scientific status of the theory. Thus, Popper is inconsistent when claiming that dogmatism may reveal the real power of a theory.

Another critical paper in the Colloquium was delivered by John Watkins. Similar to Popper, he criticized Kuhn's notion of normal science. Watkins insisted that science is essentially critical and revolutionary. He claimed that Kuhn was mistaken when he promoted normal science at the expense of revolutionary science merely because the former is common whereas the latter is rare. To show how Kuhn was mistaken in this view, Watkins made a distinction between two perspectives:

> From a sociological point of view it may be quite in order to discount something on the ground that is rare. But from a methodological point of view, something rare in science—a path-breaking new idea or a crucial experiment between two major theories—may be far more important than something going on all the time.[119]

Watkins also criticized normal science by claiming that it cannot be responsible for the emergence of scientific revolutions. Contrary to Kuhn, he asserted that some cases in the history of science reveal that the emergence of new paradigms is not relatively sudden; instead, they emerge over a relatively lengthy period of time as a response to continuous critical challenges to a theory. For instance, one can trace the long evolution of Newton's inverse square law back through Hook, Kepler, and Copernicus to Aristotle's view that bodies naturally move toward Earth's center. Thus, new paradigms emerge over a long period of time in response to continuous and critical problems.[120] However, I think that one can hardly take Watkins' case of the inverse square law as a counter-example to Kuhn's picture of scientific development. After all, this law is merely a part of Newton's mechanics. Newton has made an entire system that includes methodological, epistemological, and metaphysical components. Thus, it is incorrect to confine Newton's paradigm to the inverse square law.

119. Watkins, J. W. N. Against 'Normal Science'. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 32.
120. Ibid., p. 36.

Stephen Toulmin criticized the revolutionary aspect of paradigm change in Kuhn's description of scientific progress. He argued that what Kuhn considered scientific revolutions can be viewed as units of variation. He claimed that there is no absolute conceptual change in scientific development; instead, there is a sequence of conceptual modifications that differ in their degrees, ranging from small to large modifications but never absolute. Thus, the discontinuity aspect of Kuhn's view vanishes:

> suppose we stop thinking of Kuhn's revolutions as units of effective *change* in scientific theory, and treat them instead as units of *variation*. We will then be faced with a picture of science in which the theories currently accepted at each stage serve as starting-points for a large number of suggested variants; but in which only a small fraction of these variants in fact survive and become established within the body of ideas passed on to the next generation.[121]

Toulmin's proposition of units of variation can be compared with Bird's proposition of continuum of changes discussed above. I think that Bird was more convincing since he introduced the parameters used to classify the degrees of paradigm change. Toulmin, on the other hand, did not elaborate his discussion of units of variation. For example, he did not specify the factors that determine the degree of these units or the factors that determine their number and nature.

Imre Lakatos examined the differences between Popper's view, in which science is essentially a critical enterprise, and Kuhn's view, in which science is a single dominant paradigm interrupted by scientific revolutions. He claimed that Popper's view is rational whereas Kuhn's is irrational. He also likened Kuhn's view of paradigm change to religious conversion and claimed that Kuhn appealed to mob psychology in his description of scientific revolutions:

> For Popper scientific change is rational or at least rationally reconstructible and falls in the realm of the *logic of discovery*. For Kuhn scientific change–from one 'paradigm' to another–is a mystical

121. Toulmin, S.E. Does the Distinction between Normal and Revolutionary Science Hold Water?. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 46.

> conversion which is not and cannot be governed by rules of reason and which falls totally within the realm of the (*social*) *psychology of discovery*. Scientific change is a kind of religious change.[122]

Lakatos attempted to develop Popper's method by inventing a sophisticated version of falsificationism in terms of a view of science which he called "a methodology of scientific research programmes."[123] In doing so, Lakatos aimed to justify the important role of criticism in the progress of science and the growth of knowledge.

Paul Feyerabend criticized Kuhn's notion of normal science. He claimed that it is produced by dogmatic and narrow minded scientists. He disagreed with Kuhn's view which states that in order for a discipline to reach the scientific status, it must restrict criticism, reduce the number of rival theories to one, and produce a normal science that has this one theory as a dominant paradigm.[124] Instead, Feyerabend asserted that every scientist must follow his tendencies and there is no need to suppress even the most peculiar product of human mind. He declared that "[science] must be allowed to retain ideas in the face of difficulties; and it must be allowed to introduce new ideas even if the popular views should appear to be fully justified and without blemish."[125] For Feyerabend, this view of science is better than Kuhn's notion of normal science.

Contrary to other critics in the Colloquium, Margaret Masterman defended Kuhn's notion of normal science. She claimed that Kuhn demonstrated that science normally involves paradigm-governed and puzzle-solving activities, not falsifying activities, and that philosophers and scientists are now, in an increasing number, reading Kuhn rather than Popper:

> to such an extent, indeed, that, in new scientific fields particularly, 'paradigm' and not 'hypothesis' is now the 'O.K. word'. It is thus

122. Lakatos, I. Falsification and the Methodology of Scientific Research Programmes. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 93.
123. Ibid., p.132.
124. Feyerabend, P. Consolations for the Specialist. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 198.
125. Ibid., p. 210.

scientifically urgent, as well as philosophically important, to try to find out what a Kuhnian paradigm is.[126]

Masterman called attention to the originality of the sociological aspect of Kuhn's notion of paradigm: the paradigm is something which can function even when the theory is absent. That is, sociologically, a paradigm is a set of scientific habits; and, by adopting these habits, scientists can perform successful problem-solving activities. This can be observed in any new scientific field in which the formal theory is absent. The alternative is some techniques, pictures, and insights that are applicable in this new field. This alternative constitutes the sociological paradigm.[127]

However, Masterman criticized the ambiguity of Kuhn's notion of paradigm. She claimed that in his book *The Structure of Scientific Revolutions*, Kuhn used the term 'paradigm' in 21 different senses. She grouped them into three main categories:

(i) Metaparadigms: they provide scientists with the theoretical basis of their scientific practice. This category includes a group's beliefs, a myth, a metaphysical view of an entity, a criterion, a way of seeing the world, a map, something that governs perception, and a way that specifies a large area of nature.

(ii) Sociological paradigms: they guide the behavior of members of scientific communities. This category includes a generally accepted scientific achievement, a specific scientific achievement, a generally recognized judicial decision, and a political institution.

(iii) Construct paradigms: These are close in meaning to what Kuhn would call concrete exemplary problem solutions. This category includes a textbook, a classic work, a machine-tool factory, experimental tools, an instrumentation, an analogy, a gestalt figure, a grammatical paradigm, and an anomalous set of playing cards.[128]

126. Masterman, M. The Nature of a Paradigm. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 60.
127. Ibid., p. 69.
128. Ibid., pp. 61-65.

Masterman claimed that metaparadigms are the only kind of paradigms that Kuhn's critics in the Colloquium have considered in their criticisms. Furthermore, she was worried by the fact that many readers of Kuhn's book have mistakenly equated a paradigm with a scientific theory.

> For his metaparadigm is something far wider than, and ideologically prior to, theory . . . . His sociological paradigm . . . is also prior to theory, and other than theory, since it is something concrete and observable: i.e. a set of habits. And his construct-paradigm is less than a theory, since it can be something as little theoretic as a single piece of apparatus: i.e. anything which can cause actual puzzle-solving to occur.[129]

Masterman believed that Kuhn's treatment of preparadigm science involves confusion and an incomplete analysis. She claimed that Kuhn failed to distinguish the three relevant different stages that are characteristic of the preparadigm science period, which she called non-paradigm science, multiple-paradigm science, and dual-paradigm science. Non-paradigm science is the stage in which there is no paradigm at all. It is characteristic of the early thinking in any subject. In this stage, all facts are equally relevant with no systematic manner in which to collect them, scientists engage in philosophical discussions over fundamentals, and no real progress in any area is made. In contrast, the stage of multiple-paradigm science is characterized by the existence of many paradigms. In this stage, each school of thought has its special paradigm. These schools compete with each other and direct their publications against one another. The puzzle-solving activity that is characteristic of normal science can be established within each school, but because of the competition between rival schools, the progress attained can hardly be compared with that of single paradigm science; it is not long-run progress. The stage of multiple-paradigm science ends when one invents a novel and deeper paradigm by making a genuine unprecedented achievement that is capable of impressing and attracting scientists from other schools to adopt it. With this achievement, a single paradigm science is established, and research, which involves puzzle-solving activities, becomes more rigid, precise, and progressive. Finally, the

129. Ibid., p. 67.

dual-paradigm science stage occurs during the period of crisis. In this stage, only two paradigms compete, and it is similar to the multiple-paradigm stage except that the points of disagreement between the two paradigms are now subtler and more defined.[130]

Masterman argued that Kuhn failed to distinguish the three different stages of preparadigm science partly because he confused two states of affairs. After saying that "there can be a sort of scientific research without paradigms,"[131] which corresponds to non-paradigm science, Kuhn then added, "or at least without any so unequivocal and so binding as the ones named above [Ptolemaic astronomy (or Copernican), Aristotelian dynamics (or Newtonian), corpuscular optics (or wave optics), and so on],"[132] which corresponds to dual-paradigm science, as if these two stages are identical. It is also partly because he exclusively attached the acquisition of a paradigm to the state of single paradigm science: the "[a]cquisition of a paradigm and of the more esoteric type of research it permits is a sign of maturity in the development of any given scientific field."[133] Thus, according to Kuhn's view, the competing schools in the stage of multiple-paradigm science do not possess paradigms.[134] In the next chapter below, we shall see that Kuhn had retracted this last view.

130. Ibid., pp. 73-74.
131. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 12.
132. Ibid., p. 12.
133. Ibid., p. 12.
134. Masterman, M. The Nature of a Paradigm. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, pp. 74-75.

# Chapter 3

# Paradigms Clarified

The criticisms against the initial theory of paradigm motivated Kuhn to clarify his initial use of the concept of a paradigm. He believed that a thorough understanding of the concept of a paradigm is essential to understand his description of scientific progress as presented in his book *The Structure of Scientific Revolutions*. To that end, he distinguished between two senses of paradigm: the disciplinary matrix and exemplary problem solutions. Furthermore, Kuhn clarified the structure of scientific communities since he believed that there is an intimate relationship between the concept of a paradigm and the nature of the scientific community. In this chapter, I discuss Kuhn's responses to his critics at the London Colloquium. Then, I consider his clarification of the structure of scientific communities and his two-sense distinction of the concept of a paradigm as presented in the Postscript to his book and in his paper *Second Thoughts on Paradigms*. At the end of this chapter, I formulate a precise definition of paradigms which I will use in Chapter 4 to explain Kuhn's description of scientific development.

### 3.1 Kuhn's Responses to his Critics

In his paper *Reflections on my Critics*, Kuhn defended his view of science against the criticisms raised at the London Colloquium. He observed that the criticisms were mainly focused on four points: methodology, normal science, paradigm change, and the nature of paradigms. Kuhn believed that most of his critics misunderstood his description of scientific development; hence, he sought to further clarify his position.

Kuhn noted that his critics claimed that his method is historical and descriptive and that it relies on social psychology, whereas their own method is logical and normative. He defended his position by affirming that both his view and his critics' view rely on historical case studies and observations on scientific behaviour. The only difference is that he, in contrast to his critics, began as a historian of science to construct a theory of scientific knowledge.

> I am no less concerned with rational reconstruction, with the discovery of essentials, than are philosophers of science. My objective, too, is an understanding of science, of the reasons for its special efficacy, of the cognitive status of its theories. But unlike most

> philosophers of science, I began as an historian of science, examining closely the facts of scientific life.[135]

Regarding the social psychology aspect of his method, Kuhn argued that rules alone are inadequate to dictate the behaviour of individual scientists. For example, in theory-choice situations, shared commitments decisively influence the scientific group's behaviour, and factors such as personality, education, and past experience play a role in dictating the choice of the individual. Finally, Kuhn contended that his view of science involves normative implications:

> The structure of my argument is simple and, I think, unexceptionable: scientists behave in the following ways; those modes of behaviour have (here theory enters) the following essential functions; in the absence of an alternate mode that would serve similar functions, scientists should behave essentially as they do if their concern is to improve scientific knowledge.[136]

Kuhn then defended his view of normal science. He claimed that his critics were mistaken when they denied its existence or when they described it as an uninteresting activity compared to revolutionary science. Kuhn insisted that revolutionary science demands the existence of normal science. That is, if science is always revolutionary, then scientific revolutions cannot be distinguished. "By their nature revolutions cannot be the whole of science: something different must necessarily go on in between."[137] Furthermore, when scientists take their paradigm for granted, exploring it instead of criticizing it, they can study subtle and detailed aspects of nature. Such detailed study will ultimately lead scientists to recognize and isolate anomalies that in turn lead to crises and the initiation of revolutionary science periods. As we have observed in the previous chapter, Popper believed that scientists should attempt at all times to criticize their theories and invent alternative theories. Kuhn partly disagreed with Popper on

135. Kuhn, T. S. Reflections on my Critics. In Lakatos I, and Musgrave A (eds): Criticism and the Growth of Knowledge. Cambridge: Cambridge University Press. 1970, p. 236.
136. Ibid., p. 237.
137. Ibid., p. 242.

this point. That is, Kuhn admitted that a scientist should be critical and revolutionary, but such an attitude should be adopted only in the occasional periods of extraordinary science.

Kuhn asserted that it is often difficult to distinguish normal science from revolutionary science. One must understand the nature and structure of the scientific community's commitments before and after a paradigm change. Additionally, one must understand the manner in which the members of the community receive the change. Moreover, the structure of the scientific community must be considered:

> The gist of the problem is that to answer the question 'normal or revolutionary?' one must first ask, 'for whom?' Sometimes the answer is easy: Copernican astronomy was a revolution for everyone; oxygen was a revolution for chemists but not for, say, mathematical astronomers . . . . For the latter group oxygen was simply another gas, and its discovery was merely an increment to their knowledge.[138]

Kuhn then defended his position against the charge that his account of paradigm change implies irrationality and relativism in science. With respect to the charge of irrationality, Kuhn argued that there are three main sources that motivated his critics to raise the charge:

(i) his insistence that logic and experiment alone cannot compel scientists' choice between competing paradigms,

(ii) his insistence that the choice between competing paradigms is ultimately a community decision and that a verification, or falsification, in science does not attain until the entire scientific community converts to the new paradigm, and

(iii) his discussion of incommensurability.[139]

138. Ibid., p. 252.
139. Kuhn, T. S. Notes on Lakatos. In Buck RC, and Cohen RS (eds): PSA 1970: In Memory of Rudolf Carnap. Dordrecht: D. Reidel Publishing Company. 1971, pp. 144-146.

Kuhn insisted that the view that states that the rationality of science relies on the existence of a scientific method that dictates what scientists should do in different situations needs to be adjusted. He believed that the rationality of scientific procedures is significantly dependent on the essential aspects of scientific behaviour. In other words, rationality is illustrated by scientific behaviour.[140]

Kuhn argued that in matters of theory-choice that accompany paradigm change, competing groups cannot appeal to an argument that resembles a logical or mathematical proof. That is, in such proofs, the competing groups agree on premises and rules of inference. If two groups disagree on their final conclusions, then each group can check the steps of its proof. Since the two groups agree on the rules of inference, one of the two groups must admit that a mistake has been made and that the proof of the other group is the correct proof. However, in cases of theory-choice, this recourse to proofs is not possible because the two groups disagree on the basic premises and on the meaning and application of rules. Instead, the two groups appeal to persuasion, and Kuhn suggested that there are good reasons for a scientist to be persuaded to convert to the other paradigm. These reasons are objective and do not much differ from the usual reasons listed by philosophers of science, including simplicity, accuracy, scope, and fruitfulness, among others. According to Kuhn, these reasons constitute values or criteria for the assessment and choice of theories; they must not be viewed as rules that dictate scientists' choices. These values are shared by the members of the scientific community and acquired from the study of exemplary problem solutions that illustrate them in applications.[141] For Kuhn, the rationality of theory choice relies on the persistence of the shared values that are used to evaluate and compare theories.[142]

Kuhn claimed that such values may eventually lead to the same direction and thus declare the triumph of one paradigm over another. Nevertheless, Kuhn called attention to two points that must be taken into account when one considers the debate between competing paradigms. First, although these values are constitutive of good reasons, they are not univocal. One value may favour one paradigm, whereas another may favour its rival. "In such cases of value-conflict (e.g. one theory is simpler but the

140. Ibid., p. 144.
141. Kuhn, Reflections on my Critics, op-cit., pp. 260-261.
142. McMullin, Rationality and Paradigm Change in Science, op-cit., pp. 57-58.

other is more accurate) the relative weight placed on different values by different individuals can play a decisive role in individual choice."[143] Second, although these values are shared by the members of a scientific community, different scientists may use a single value in different ways; hence, different scientists may reach different conclusions, even when they apply a single value.

> More important, though scientists share these values and must continue to do so if science to survive, they do not all apply them in the same way. Simplicity, scope, fruitfulness, and even accuracy can be judged quite differently (which is not to say they may be judged arbitrarily) by different people.[144]

Moreover, Kuhn insists that the variability of judgments involved in the previous two points is essential to scientific progress. If all members of a scientific community apply different values in exactly the same manner, then there will be little progress in science. That is, on the one hand, if all scientists agree to adhere to the old paradigm, then the new paradigm will not have the chance to develop; hence, it will not be able to attract adherents. On the other hand, if all scientists convert to the new paradigm, then science will jump from one paradigm to another at every anomaly that scientists encounter; hence, no paradigm will develop such that it can be used to study natural phenomena in a subtle and detailed manner.[145]

Regarding the charge of relativism, Kuhn observed that there are two senses of relativism of which his critics accused him. In the first sense, his critics claim that since successive paradigms are incommensurable, there is no progress in a paradigm change; it is a mere change. Kuhn responded to this charge by insisting that his view of scientific progress is essentially evolutionary. He used a metaphor of an evolutionary tree that represents scientific progress:

> Imagine . . . an evolutionary tree representing the development of the scientific specialties from their common origin in, say, primitive

143. Kuhn, Reflections on my Critics, op-cit., p. 262.
144. Ibid., p. 262.
145. Worrall, J. Normal Science and Dogmatism, Paradigms and Progress: Kuhn 'versus' Popper and Lakatos. In Nickles T (ed): Thomas Kuhn. Cambridge: Cambridge University Press. 2003, p. 94.

> natural philosophy. Imagine . . . a line drawn up that tree . . . to the tip of some limb without doubling back on itself. Any two theories found along this line are related to each other by descent. Now consider two such theories, each chosen from a point not too near its origin [i.e., after the science has become mature]. I believe it would be easy to design a set of criteria—including maximum accuracy of predictions, degree of specialization, number (but not scope) of concrete problem solutions—which would enable any observer involved with neither theory to tell which was the older, which the descendant. For me, therefore, scientific development is, like biological evolution, unidirectional and irreversible.[146]

Thus, Kuhn provided us with objective criteria that enable any scientist to judge which theory is superior over the other. He extended the list of these criteria to include the degree of precision and articulation, the number of matching points between theory and nature, and the theory's efficacy in solving puzzles in different applications.[147]

I believe that there are two inconsistent views in Kuhn's position. First, Kuhn previously likened an individual's adoption of a new theory to a conversion experience. However, this is inconsistent with his claim that there are *objective* criteria for judging the superiority of one theory over another and that one can use these criteria to objectively decide which theory is better, which is certainly not similar to a conversion experience. Second, Kuhn previously claimed that these criteria must be viewed as values and that different values may dictate different conclusions. This claim is inconsistent with his assertion that the criteria are capable of enabling any observer to objectively decide which theory in Kuhn's evolutionary tree is the older and which is the descendant.

With respect to the second sense of relativism, Kuhn admitted that he is a relativist. In this second sense, Kuhn's critics claim that his view denies the progress of science toward the truth. Kuhn argued that there are two problems with the view that a new theory more closely approaches the truth than an older theory. First, to say, for

146. Kuhn, Reflections on my Critics, op-cit., p. 264.
147. Kuhn, Logic of Discovery or Psychology of Research?, op-cit., p. 20.

instance, that a new field theory in physics more closely approaches the truth than an old matter theory implies that nature is more like a field than like matter. However, it is not clear in this case what the phrase 'more like' means. Second, an investigation of the historical record shows that the ontologies of successive theories do not approach a limit. For instance, the ontology of Einstein's theory of general relativity resembles that of Aristotle's theory more than that of Newton's theory.[148]

Kuhn also clarified his notion of incommensurability. He compared it with the process of translation. Just like a translator cannot make a literal translation from a given language to another, so scientists cannot make a point-by-point comparison between two successive theories because there is no theory neutral language by which one can make the comparison. Thus, there is always some information lost in a translation process, which prevents *full* communication. But this does not mean that the adherents to competing theories cannot communicate with each other. Kuhn argued that the competing groups can first attempt to identify the terms which are used unproblematically in each theory but are centers of breakdown of communication. Next, they can appeal to their common everyday vocabularies in order to clarify the troublesome terms. In this way, the members of each group will learn to translate the other's theory and its implications into their own language and at the same time to describe in their language the world to which that theory can be applied. This is actually what historians of science regularly do when they consider out-of-date scientific theories.[149]

Kuhn identified two sources of incommensurability. First, the meaning of terms shared between two incommensurable theories changes in radical ways during a paradigm shift. Second, there is no adequate neutral linguistic manual by which one can make a point-by-point translation between two rival theories because such manuals are expressed in terms of particular theories that interpret the world differently.[150] Kuhn states that:

> in the transition from one theory to the next words change their meanings or conditions of applicability in subtle ways. Though most of the same signs are used before and after a revolution—e.g., force,

148. Kuhn, Reflections on my Critics, op-cit., p. 265.
149. Ibid., pp. 268-269.
150. Ibid., p. 266.

> mass, element, compound, cell—the ways in which some of them attach to nature has somehow changed. Successive theories are thus, we say, incommensurable.[151]

Regarding the nature of paradigms, Kuhn admitted that he has used the term in many different senses in his book *The Structure of Scientific Revolutions*. He appreciated Masterman's work in demonstrating the various senses of the concept of a paradigm. As observed above, Masterman classifies these senses into three distinct categories. Kuhn, however, distinguishes two main senses of the term 'paradigm': the disciplinary matrix and exemplary problem solutions.[152] I consider this two-sense distinction in detail below.

### 3.2 Scientific Communities Clarified

Since there is an intimate relationship between the concept of paradigm and the nature and structure of scientific communities, Kuhn attempted to clarify his view of scientific communities. In the Postscript to his book, Kuhn was concerned with the circularity involved in defining paradigms. A paradigm is what the members of a scientific community share, and conversely, a scientific community is defined by a shared paradigm.[153] One could resolve this circularity by insisting that the content of science has priority. Thus, different groups in science stem from the different theories and techniques that they employ. Consequently, a scientific group is defined by a common paradigm and not vice versa.[154]

However, Kuhn resolved the circularity differently. He claimed that "[s]cientific communities can and should be isolated without prior recourse to paradigms; the latter can then be discovered by scrutinizing the behavior of a given community's members."[155] The problem of isolating different scientific groups concerned many

151. Ibid., pp. 266-267.
152. Kuhn, Second Thoughts on Paradigms, op-cit., pp. 297-298.
153. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 175.
154. Musgrave, A. Kuhn's Second Thoughts. In Gutting G (ed): Paradigms and Revolutions: Appraisals and Applications of Thomas Kuhn's Philosophy of Science. Notre Dame and London: University of Notre Dame Press. 1971, p. 39.
155. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 175.

sociologists of science. Kuhn cited some of their studies, including those conducted by Diana Crane and Price and Beaver. Crane adopted a method that isolates different groups by considering the names listed in a bibliography,[156] whereas Price and Beaver use a method of investigating the membership lists, preprints, and memos received by members of different groups.[157] These sociologists of science claim that their methods are objective in the sense that they can be used without considering the scientific content of scientific groups' subjects.

Kuhn believed that such sociological methods need to be developed and tested further; he did not adopt any of them. Instead, he proposed that

> [a] scientific community consists . . . of the practitioners of a scientific specialty. To an extent unparalleled in most other fields, they have undergone similar educations and professional initiations; in the process they have absorbed the same technical literature and drawn many of the same lessons from it. Usually the boundaries of that standard literature mark the limits of a scientific subject matter, and each community ordinarily has a subject matter of its own.[158]

The members of a scientific group aim to achieve a set of common goals. The relative fullness of communication and relative unanimity on professional judgments are characteristics of a group.[159]

Scientific groups can be identified by the subject matter of their study, such as the groups of physicists, astronomers, and mathematicians, among others. However, Kuhn asserted that such identification is not always possible. For example, some scientific subjects belong to different scientific groups at different times, such as the study of heat. Kuhn admitted that if he had the chance to rewrite his book, he would begin by

156. Crane, D. Social Structure in a Group of Scientists: A Test of the 'Invisible College' Hypothesis. American Sociological Review. 34. 1969, p. 338.
157. Price, D. J., and Beaver, D. B. Collaboration in an Invisible College. American Psychologist. 21. 1966, p. 1011.
158. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 176.
159. Ibid., p. 176.

considering the structure of scientific communities instead of the subject matter of their study.[160]

According to Kuhn, there is a subtle difference between the community of natural scientists and that of social scientists. The community of natural scientists is closed in the sense that their professional discipline is esoteric, isolated, and somewhat self-contained. "Science is not the only activity the practitioners of which can be grouped into communities, but it is the only one in which each community is its own exclusive audience and judge."[161] Social scientists, on the other hand, seek to communicate with an audience that is outside their own community. Kuhn believed that the emergence of paradigmatic activities that are characteristic of mature natural sciences is partly because the communities of such sciences are closed in the sense just discussed.

Kuhn argued that scientific communities exist at several levels. The highest level is the community of all natural scientists. A lower level is the communities of physicists, chemists, astronomers, and so on. These communities are divided into sub-communities of nuclear physicists, organic chemists, and radio astronomers, among others. Such sub-communities are further divided into small groups of specialists to form communities that consist of a hundred members or so, sometimes even fewer. Kuhn suggested that these last groups are the units that produce scientific knowledge.[162]

As observed in the previous chapter, Popper criticized the view of normal science as being guided by a single paradigm by claiming that there has been continuing disagreement and debate over theories of matter since antiquity into the present. Kuhn argued that with his new view of the micro-community structure of science, this claim should not be considered a counterexample. Different small groups of specialists may enter into debates over theories of matter without affecting their overall commitment to the single dominant paradigm of their scientific discipline.[163] I think that Kuhn's new view is inconsistent with his previous position. That is, he previously claimed in his book that debates over fundamentals cease during the period of normal science, but then it seems that he allowed for such debates to exist. However, I suggest that this

160. Kuhn, Reflections on my Critics, op-cit., p. 252.
161. Ibid., p. 254.
162. Kuhn, The Structure of Scientific Revolutions, op-cit., pp. 176-177.
163. Ibid., p. 179.

inconsistency could be avoided if Kuhn allowed for debates over *only* metaphysical commitments, which include commitments to different theories of matter.

Kuhn then called attention to the property of universal acceptance associated with paradigms. In his book *The Structure of Scientific Revolutions* and in his paper *The Essential Tension*, Kuhn associated the notion of paradigm with that of normal science. Normal science is a research activity that relies on a universal consensus among all participating scientists. The core of this consensus is the paradigm that guides and directs scientists in their research activities. In other words, the special nature of normal research is explained by the shared paradigm. Before normal science, a period of a number of competing scientific schools exists. Kuhn called it the pre-paradigm period. There is no universal consensus among the proponents of different rival schools; each school competes for domination. Thus, Kuhn described the transition from the pre-paradigm period to the period of normal science as the acquisition or emergence of a paradigm.[164]

However, in the Postscript to his book, Kuhn retracted universal consensus as a property of the concept of a paradigm. He now claimed that each scientific school may have an internal consensus, i.e., each school has its special paradigm. "The members of all scientific communities, including the schools of the 'pre-paradigm' period, share the sorts of elements which I have collectively labeled 'a paradigm'."[165] Thus, the transition to normal science need not be associated with the first emergence of a paradigm. What occurs in the transition to normal science is not the acquisition of a paradigm but rather a change in the nature of paradigms. Only universal paradigms permit the tackling of esoteric and advanced research problems and render science its special efficacy with which we are all familiar.[166]

### 3.3 Disciplinary Matrix

As we have seen in the previous chapter, many critics accuse Kuhn of using the term paradigm in an ambiguous manner in his book *The Structure of Scientific Revolutions* and in the papers composed around the same time. Kuhn admitted that he was unaware

164. Ibid., p. 12.
165. Ibid., p. 178.
166. Ibid., p. 178.

of the expansion of the concept of a paradigm that occurred in his early works. This motivated him to clarify the concept. He began by asking the following question: after identifying a community of practitioners of a scientific specialty, "[w]hat shared elements account for the relatively unproblematic character of [their] professional communication and for the relative unanimity of [their] professional judgment?"[167] Kuhn gave two answers that correspond to the two senses of paradigm that he later distinguished. The first sense is global, encompassing all shared commitments of a scientific community, including shared theories, techniques, beliefs, scientific values, and so on. This is the broad sense of paradigm. Kuhn called it the disciplinary matrix—*disciplinary* because it is the common possession of all scientists of a given discipline and *matrix* because it is composed of distinct components or elements. Kuhn claimed that there are many elements of the disciplinary matrix that are used in his book, but he paid special attention to the following key elements:

(i) symbolic generalizations,

(ii) models,

(iii) scientific values, and

(iv) exemplary problem solutions, or exemplars.[168]

This last element is the second, narrow sense of paradigm and is a subset of the first global sense.[169] I consider this second sense of paradigm in detail in the next section.

Kuhn defined symbolic generalizations as the formal or readily formalizable propositions that include the formal representations of the laws of nature and the basic equations of scientific theories. He insisted that these propositions, when considered as an element of the disciplinary matrix, must be viewed as uninterpreted symbols divorced from all empirical meanings. Thus, in this sense, symbolic generalizations permit scientists to use logic and mathematics to analyze their puzzles during their practice of normal science.[170] The reason Kuhn separated symbolic generalizations

167. Kuhn, Second Thoughts on Paradigms, op-cit., p. 297.
168. Ibid., p. 297.
169. Ibid., p. 297.
170. Ibid., pp. 297-298.

from their empirical meanings is that the consensus of a scientific community over the laws of nature and basic equations has two distinct aspects. The first aspect involves the general agreement among the members of a scientific community over the logical form of laws and equations, i.e., over symbolic generalizations. The second aspect involves the empirical interpretation of these pure logical forms. Kuhn claimed that different members of a community may agree on symbolic generalizations but disagree on the empirical meanings that must be attached to them.[171] Therefore, Kuhn was on the right track when he distinguished between these two aspects of consensus over laws and equations. As we shall see soon, the second aspect constitutes the fourth element of the disciplinary matrix, exemplary problem solutions.

Regarding models, Kuhn argued that the members of a scientific community share two kinds of them. The first kind is heuristic models. A phenomenon from a given class may be viewed as though it were another phenomenon from a different class. For example, the electric circuit may be viewed as a steady-state hydrodynamic system, or the molecules of a gas may be regarded as a collection of colliding billiard balls. The second kind of models is ontological or metaphysical models. These are beliefs about what the basic constituents of the world are and what its basic characteristics are. For example, heat is the kinetic energy of the particles that constitute a body, or the world consists of matter in motion.[172] Kuhn claimed that both kinds of models perform the same functions for scientists. Both are used to identify unsolved puzzles and to judge the proposed solutions.[173] Models can perform these functions because they enable scientists to use similarity relations. On the one hand, heuristic models are used as a source of external similarity relations, that is, the relations between phenomena that belong to different ontological classes. On the other hand, ontological models are used as a source of internal similarity relations, that is, the relations between phenomena of the same ontological class. These two kinds of similarity relations permit scientists to employ concepts and techniques from one situation in another similar situation.[174] Kuhn noted that models are different from the other elements of the disciplinary matrix in one aspect. Members of a scientific community *frequently* agree on such models but not *always*. In certain episodes of scientific development one may find

171. Hoyningen-Huene, Reconstructing Scientific Revolutions, op-cit., p. 146.
172. Kuhn, Second Thoughts on Paradigms, op-cit., pp. 297-298.
173. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 183.
174. Hoyningen-Huene, Reconstructing Scientific Revolutions, op-cit., p. 147.

coherent scientific research traditions without consensus on basic ontological models.[175]

The third element of the disciplinary matrix is values. Kuhn asserted that many features of scientific progress can be understood by considering the values that the members of scientific communities hold. Unlike the other elements of the matrix, values do not substantially vary over time, and the same value system may be shared by different scientific communities, which may explain the fact that all natural scientists form a large single community are socially united by their possession of a common value system.[176] According to Kuhn, scientists usually employ this common value system to evaluate theories. This process of evaluation consists of two levels. The first level is the evaluation of the manner in which individual scientists apply their theories. This process occurs at all times during the practice of normal science. The second level is the evaluation of the theory as a whole. This process occurs at the occasional times of crises during which two rival theories are evaluated.[177]

Kuhn claimed that the scientific values that scientists employ in their evaluations of theories are not different from those usually considered by philosophers of science. In his paper *Objectivity, Value Judgment, and Theory Choice*, Kuhn considered five of these values in detail:

(i) Accuracy: theoretical predictions should be in reasonable agreement with observational and experimental results. The agreement should be both quantitative and qualitative.

(ii) Consistency: a theory should not contain internal contradictions. It should also be consistent with other accepted theories.

(iii) Scope: a theory should be applicable to a wide range of phenomena.

(iv) Simplicity: a theory should be able to connect apparently isolated and independent phenomena and provide a simple conceptual order to study them.

175. Kuhn, Reflections on my Critics, op-cit., p. 255.
176. Ibid., p. 148.
177. Kuhn, The Structure of Scientific Revolutions, op-cit., pp. 184-185.

(v) Fruitfulness: a theory should shed light on new phenomena and disclose new relationships between previously studied phenomena.[178]

Exemplars, the fourth element of Kuhn's disciplinary matrix, are "a set of recurrent and quasi-standard illustrations of various theories in their conceptual, observational and instrumental applications. These are the community's paradigms, revealed in its textbooks, lectures and laboratory exercises."[179] From the study of exemplars, the student learns how to apply laws and theories to different situations that he will encounter later in his research. Thus, exemplars provide scientific theories with empirical content.

Hoyningen-Huene suggested that Kuhn's use of the term 'elements' of the disciplinary matrix is misleading. He argued that such terminology implies that the relationship between different elements and the disciplinary matrix is similar to that between subsets and sets. In other words, the view of symbolic generalizations, models, values, and exemplary problem solutions as elements or components of a matrix implies that these elements are separable and independent of each other. However, according to Hoyningen-Huene, the four elements of the disciplinary matrix should be viewed as inseparable moments of a single unity. He took exemplary problem solutions, or paradigms in the narrow sense, as the central moment and examined their relation with the other moments of the disciplinary matrix.[180] In this manner, as we shall soon observe, Hoyningen-Huene claimed that he was able to provide the reason behind the expansion of the concept of a paradigm that took place in Kuhn's writings.

First, Hoyningen-Huene considered the relationship between symbolic generalizations and exemplary problem solutions. He argued that the latter do not contain all the empirical meanings involved in a theory application; instead, symbolic generalizations play a role in fixing the meanings of empirical concepts. For example, if a problem of planetary motion is solved by applying Newton's law of gravitation,

178. Kuhn, T. S. Objectivity, Value Judgment, and Theory Choice. In Kuhn TS (ed): The Essential Tension: Selected Studies in Scientific Tradition and Change. Chicago and London: The University of Chicago Press. 1977, pp. 321-322.
179. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 43.
180. Hoyningen-Huene, Reconstructing Scientific Revolutions, op-cit., p. 155.

then another problem of planetary motion will not be viewed as being similar to the first if it is solved by applying another law, i.e., the two problems will not help fix the meanings of empirical concepts for students.[181]

Hoyningen-Huene then considered the relationship between models and exemplary problem solutions. Regarding heuristic models, he claimed that one can understand the analogies involved in them only by reference to exemplars. Similarly, the content of ontological models that are shared by the members of a scientific community can be appropriately understood only by reference to exemplars that illustrate these models.[182]

Similar remarks may be made for the relationship between scientific values and exemplars. That is, the values that are shared by scientists are best demonstrated by reference to concrete problem solutions. Furthermore, students acquire these shared values only by studying exemplary problems. Without exemplars, students can hardly gain a sense of what counts as an accurate solution or as a simple problem.[183]

Therefore, Hoyningen-Huene emphasized on the following conclusion:

> What follows from all this is that we can't regard the relationship between symbolic generalizations, models, values, and concrete problem situations on the one hand and the disciplinary matrix on the other as that of elements or subsets to a set. The relationship between the former items is that of *linked moments of a single unity*; though individual moments can be distinguished, they can't even be conceived as separate.[184]

Alexander Bird arrived at a somewhat similar conclusion but by a different route. He argued that if the components of a disciplinary matrix are separable and independent of each other, then an exemplar from this matrix can be combined in another matrix involving different symbolic generalizations, models, and values. In this case, the notion of paradigm change will be ambiguous. That is, if one of the non-exemplar

181. Ibid., p. 156.
182. Ibid., p. 157.
183. Ibid., p. 157.
184. Ibid., p. 157.

parts of a disciplinary matrix is changed, then we will have a change of paradigm as a disciplinary matrix but no change of paradigm as exemplar.[185]

Hoyningen-Huene claimed that the distinction that he has made between separate elements and linked moments of the disciplinary matrix is essential to understand the development of the concept of a paradigm in Kuhn's writings. He argued that Kuhn originally defined paradigms as concrete exemplary problem solutions. In this sense, paradigms constitute the core of scientific consensus that guides scientists in their normal research. However, as observed above, exemplary problem solutions involve symbolic generalizations, models, and values as moments. When exemplary problem solutions perform their functions in normal science, these implicit moments become explicit. Therefore, paradigms in the narrow sense transform into paradigms in the broad sense, i.e., the core of consensus transforms into the entire consensus. The expansion of the concept of a paradigm that took place in Kuhn's writings is due to this transformation. Thus, Kuhn's mistake is that he failed to distinguish the various moments involved in exemplars.[186]

Dudley Shapere made a somewhat similar argument. He argued that Kuhn's distinction of the two senses of paradigms "is of little help to those who found the earlier concept of 'paradigm' obscure."[187] The problem is that Kuhn did not clarify the relationship between exemplary problem solutions, that is, paradigms in the narrow sense, and the disciplinary matrix, that is, paradigm in the broad sense. Thus, Kuhn failed to show how paradigm in the broad sense is delivered to students through their study of paradigms in the narrow sense.[188] Indeed, Kuhn insisted on the distinction between the components of the disciplinary matrix, but he did not pay sufficient attention to the unity that underlies the different components.

### 3.4 Exemplars

According to Kuhn, exemplary problem solutions are the basic units of scientific knowledge. They are the standard problem solutions that the student encounters during

185. Bird, Thomas Kuhn, op-cit., p. 76.
186. Hoyningen-Huene, Reconstructing Scientific Revolutions, op-cit., pp. 157-158.
187. Shapere, D. The Paradigm Concept. In Shapere D (ed): Reason and the Search for Knowledge: Investigations in the Philosophy of Science. Dordrecht: D. Reidel Publishing Company. 1971, p. 53.
188. Ibid., p. 53.

his period of education. Based on exemplars, scientists conduct their research during their practice of normal science. Kuhn insisted that exemplars are "prior to the various concepts, laws, theories, and points of view that may be abstracted from [them]."[189]

Frederick Suppe analyzed exemplars and found that they consist of the following six components:

(i) an informal description of an experimental setup,

(ii) the appropriate formula for a particular symbolic generalization in a given problem,

(iii) a statement of the experimental data,

(iv) a canonical redescription of the data in terms of the variables of the symbolic generalization,

(v) a description that enables one to translate the experimental data from the original informal description to the canonical redescription, and

(vi) various logical and mathematical manipulations that enable one to obtain the required results.[190]

Suppe claimed that these components reveal some important characteristics of exemplars. The various logical and mathematical manipulations of component (vi) enable the student to manipulate the different variables of symbolic generalizations to arrive at the right solution. Thus, the student learns how to use certain techniques, tricks, and approximations that enable him to attach symbolic generalizations to nature. Furthermore, these techniques enable the student to express the canonical redescriptions of the experimental data (iv) in terms of the symbolic generalizations of the theory.[191]

Thus, from the study of exemplars, the student learns how to apply symbolic generalizations to different situations. When the student studies exemplars and

189. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 11.
190. Suppe, F. Exemplars, Theories, and Disciplinary Matrixes. In Suppe F (ed): The Structure of Scientific Theories. 2nd ed. Chicago and London: University of Illinois Press. 1977, p. 484.
191. Ibid., pp. 484-485.

attempts to solve new problems, he develops resemblance or similarity relationships. These similarity relationships permit the student to model the solutions of previously solved exemplars on new unsolved problems. Thus, the basic function of exemplars during the period of normal science is to guide scientists in their research by developing their ability to see similarity relationships between different problem situations. These learned similarity relationships enable scientists to model one problem solution on another.[192] Thus, we may say that normal scientific research proceeds by moving from instance to instance and by employing analogies between these instances.[193]

Kuhn observed three different domains in which similarity classes may be formed:

(i) Different sensory perceptions of a single object. In this domain, a similarity class is formed by recognizing the identity of the object.

(ii) Different sensory perceptions of different objects. Here, a similarity class is formed between different objects that belong to the same species. Kuhn called such similarity classes natural families.

(iii) Different problem situations that can be treated by the same symbolic generalization.[194]

Similarity relationships belonging to different domains may depend on each other. For example, the formation of natural families may depend on the perception of similarity relationships that enable one to recognize the identity of individual objects. Also, the formation of similarity relationships between problem situations may depend on the formation of natural families of objects. This case happens when some objects can be identified only in a certain class of problem situations, or when such problem situations are obtained only if these objects are given.[195]

Kuhn insisted that the ability to see similarities between different problems is not based on a set of correspondence rules; instead, the "basic criterion is a perception of

192. Kuhn, Second Thoughts on Paradigms, op-cit., p. 306.
193. Barnes, B. Thomas Kuhn and the Problem of Social Order in Science. In Nickles T (ed): Thomas Kuhn. Cambridge: Cambridge University Press. 2003, p. 128.
194. Kuhn, Second Thoughts on Paradigms, op-cit., pp. 308-310.
195. Kuhn, Reflections on my Critics, op-cit., pp. 273-274.

similarity that is both logically and psychologically prior to any of the numerous criteria [such as correspondence rules] by which that same identification of similarity might have been made."[196] To demonstrate the principle of the perception of similarity relationships, Kuhn asked us to imagine a child walking in a zoo with his father. The father attempts to teach his child the identification of swans, geese, and ducks. The pedagogical tool is ostension. The child learns to identify different birds by watching his father point to the three classes of birds. The father then asks his child to do the same, and if the child makes a mistake, his father must correct him. By this process of ostension and correcting, the child learns to identify swans, geese, and ducks. He develops similarity relationships that enable him to group similar birds into one cluster and label it with a name, e.g., the cluster of swans. Therefore, when the child sees a bird that resembles the birds in the cluster of swans, he will identify this bird as a swan.[197] According to Kuhn, the child

> has learned to apply symbolic labels to nature without anything like definitions or correspondence rules. In their absence he employs a learned but nonetheless primitive perception of similarity and difference. While acquiring the perception, he has learned something about nature. This knowledge can thereafter be embedded, not in generalizations or rules, but in the similarity relationship itself.[198]

The swans, geese, and ducks that the child encounters during the walk with his father are analogous to exemplars. The child learns similarity relationships that enable him to attach the same word to similar birds. By analogy, through the study of exemplars, the student learns similarity relationships that enable him to apply the same symbolic generalization to similar problems. For example, through the study of problems such as the inclined plane and the oscillating pendulum, the student learns to identify other Newtonian problems and to write the right formulations for their solutions.[199]

196. Kuhn, Second Thoughts on Paradigms, op-cit., p. 308.
197. Ibid., pp. 309-312.
198. Ibid., p. 312.
199. Ibid., p. 313.

However, I think that the analogy is not appropriate. That is, the child learns how to attach words to things by a process of ostension. However, this process can hardly be taken to account for how the student applies symbolic generalizations to concrete problems. Symbolic generalizations involve logical and mathematical relations between various variables, and reflection is required to construct the right formulation for a given problem. Thus, applying symbolic generalizations to nature is a complicated process that requires a great deal of reflection; hence, it is not analogous to the process of attaching words to things.

Alexander Bird raised an objection against Kuhn's ignorance of the role of reflection in the identification and assessment of problem solutions. A scientific law can be expressed in many different forms. For example, Newton's law of motion $F = ma$ has different forms depending on the problem situation: in case of free fall, the law has the form $mg = d^2s/dt^2$; in case of a simple pendulum $mg\sin\theta = - ml\ (d^2\theta/dt^2)$; and for a pair of harmonic oscillators $m_1(d^2s_1/dt^2) + k_1s_1 = k_2(s_2 - s_1 + d)$, and so on.[200] Kuhn asks how does the student arrive at the right form? Kuhn's answer is that the student learns to recognize similarity relationships between different problem situations and the exemplars which he studies during his education.

> The law-sketch, say $F = ma$, has functioned as a tool, informing the student what similarities to look for, signaling the gestalt in which the situation is to be seen. The resultant ability to see a variety of situations as like each other, as subjects for $F = ma$ or some other symbolic generalization, is, I think, the main thing a student acquires by doing exemplary problems, whether with a pencil and paper or in a well-designed laboratory.[201]

According to Bird, Kuhn's view could be right if similarity relationships help the student specify which approach that he should adopt in solving a problem and which form of the formal law is most suitable for the given problem. But this does not mean that the solution of a problem is to be identified and assessed only by appealing to similarity relationships. Indeed, the student can use logical arguments and

200. Kuhn, The Structure of Scientific Revolutions, op-cit., p. 188.
201. Ibid., p. 188.

mathematics, whose application could be mechanical, to show that the different forms of Newton's law of motion can be derived from the basic formula $F = ma$, i.e., the student does not need to *intuit* their similarity. In order to arrive at the appropriate form of the formal law $F = ma$ it is often sufficient to know what assumptions are required for the derivation of that form.[202]

Kuhn is acknowledged for calling our attention to the role of learned similarity relationships in scientific assessment. However, it is an exaggeration to suppose that similarity relationships alone are sufficient to account for all scientific assessment. Bird suggests that a more plausible view of science would involve both learned similarity relationships and reflection.[203]

Paradigms, in the sense of exemplary problem solutions, have normative functions since they guide scientists in their practice of normal science; they are not merely accepted problem solutions. We may identify four normative functions for paradigms in the sense of exemplars:

(i) the semantic function,

(ii) problem identification,

(iii) solution assessment, and

(iv) solution identification.[204]

The semantic function of exemplars can be noted in scientists' practice of normal science. Scientists employ a specific conceptual system, or what Kuhn calls a "lexicon,"[205] when they conduct normal-science research. Some concepts of the lexicon are empirical. These concepts are directly applied to experimental and observational situations. However, the lexicon also contains abstract theoretical concepts, e.g., the concept of electric potential in physics, which cannot be directly

202. Bird, Thomas Kuhn, op-cit., pp. 87-88.
203. Ibid., p. 88.
204. Ibid., pp. 68-69.
205. Kuhn, T. S. Commensurability, Comparability, Communicability. In Conant J, and Haugeland J (eds): The Road Since Structure: Philosophical Essays, 1970-1993, with an Autobiographical Interview. Chicago and London: The University of Chicago Press. 1983, p. 52.

applied. The semantic function of exemplars is to provide such theoretical concepts with meanings. That is, one cannot adequately understand a theoretical concept without studying a number of exemplary problem solutions in which this concept is involved.[206]

Regarding the second function, exemplars help scientists identify new research problems for future exploration. Scientists can recognize the problematic character of a new research problem only if they have a background of previously accepted exemplary problems. Through similarity relationships, scientists use the problematic character of a previously accepted exemplar to construct new research problems. Furthermore, exemplars may also help scientists assess the relative importance of new research problems so that they direct their efforts to problems that are worth working on.[207]

The third function of exemplary problem solutions is the assessment of the proposed solutions to new puzzles. Previously solved exemplary problems provide scientists with standards, whether theoretical, instrumental, or experimental, that enable them to judge the acceptability of proposed puzzle-solutions.[208]

Finally, exemplars help scientists arrive at the right solutions to new research problems. When scientists study the solutions to previously solved problems, they become able to recognize clues that help them to see the world such that appropriate solutions to new problems become evident. For example, a trained physicist is able to recognize that a particular form of Newton's law of motion is appropriate for the solution to a new puzzle that he may encounter.[209]

Bird noted that the four normative functions of exemplary problems can be classified into two kinds of functions. The first kind, which Bird calls the 'puzzle-solving' functions, involves problem identification, solution identification, and solution assessment. The second kind is the semantic function. In one sense, the semantic function is different from the puzzle-solving functions. For the puzzle-solving functions may all be fulfilled at the same time by one exemplar, but that same exemplar may not fulfill the semantic function of giving meaning to empirical

206. Bird, Thomas Kuhn, op-cit., pp. 68-69.
207. Hoyningen-Huene, Reconstructing Scientific Revolutions, op-cit., pp. 160-161.
208. Ibid., p. 162.
209. Bird, Thomas Kuhn, op-cit., p. 71.

concepts. In order to perform the semantic function, a given exemplar has to be a perceptual entity, for instance, it has to be an object or an experimental situation, since empirical concepts are understood by perceptual contact. Yet, not all exemplars are perceptible; instead, they usually constitute a chapter in a textbook or an article in a scientific journal. Despite the fact that such exemplars may involve some perceptible entities such as figures, diagrams, and instrumental arrangements, these perceptible entities considered alone are not sufficient to perform all of the puzzle-solving functions. Therefore, not all exemplars that perform the puzzle-solving functions simultaneously perform the semantic function.[210]

The normative functions of paradigms in the sense of exemplars may explain the persistence of the consensus of the scientific community during the period of normal science. These functions act as conservative forces that operate on two levels: the social level and the individual level. Regarding the social level, exemplars play a fundamental role in the training and education of students. To be a scientist, the student is asked to study and solve several exemplary problems, whether theoretical or experimental. These exemplary problems develop the skills of the student by performing their normative functions. The exemplary problem solutions are common to all universities around the world. Thus, the uniformity in scientific education guarantees that if a student fails in his training, then he will not be accepted into the scientific community. Regarding the individual level, exemplars develop the ability of the student to see similarity relationships between different problems. The learned similarity relationships motivate the student to consider problems that are similar to what he has studied before and to produce conservative solutions that are similar to the generally accepted exemplary solutions.[211]

However, the normative functions of exemplars have a negative consequence. They restrict the vision of the scientist to certain features of the world and his skills of solving problems to certain standard techniques. This restriction can be useful for the practice of normal science since it focuses the attention of the scientist on only significant problems and it maintains uniformity in the techniques of problem

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210. Ibid., p. 83.
211. Ibid., pp. 79-81.

solutions. Nevertheless, this restriction prevents the scientist from achieving new discoveries and arriving at novel solutions.[212]

I think that the explanation of the persistence of normal science in terms of exemplars becomes clear if we consider Hoyningen-Huene's suggestion of taking the different components of the disciplinary matrix as inseparable moments of a single unity, in which exemplars form the central moment.[213] That is, shared exemplars involve symbolic generalizations, models, and scientific values as implicit moments. When exemplars perform their normative functions, at both the social and the individual levels, these implicit moments, which constitute what scientists share and maintain during their practice of normal science, become explicit. Therefore, the practice of normal science is conservative, at both the social and the individual levels, provided that paradigms, in the sense of exemplars, perform their normative functions. At this point, I think that I can formulate a precise definition of paradigms. Paradigms are exemplary problem solutions that are generally accepted by the members of a scientific community, and they involve the other components of the disciplinary matrix (symbolic generalizations, models, and values), to which the members of a scientific community are committed, as implicit moments. These implicit moments become explicit when exemplary problem solutions perform their four normative functions—the semantic function, problem identification, solution assessment, and solution identification—in normal science.

212. Wray, K. B. Kuhn and the Discovery of Paradigms. Philosophy of the Social Sciences. 41(3). 2011, p. 391.
213. Hoyningen-Huene, Reconstructing Scientific Revolutions, op-cit., p. 157.

# Chapter 4

# Explaining Kuhn's Description of Scientific Development in terms of the Precise Definition of Paradigms

In Chapter 1, I discussed Kuhn's description of scientific development. We noticed that a scientific discipline develops in a circular pattern. First, normal science persists over a period of time till it breaks down in the period of crisis. Then, a period of revolutionary science commences which ultimately leads to the emergence of a new paradigm. With that new paradigm a new period of normal science begins. I believe that an adequate explanation of this circular pattern should explain three aspects:

(i) the persistence of normal science,

(ii) the break-down of normal science, and

(iii) the re-establishment of normal science.

In Chapter 3, I formulated a precise definition of the concept of a paradigm. In what follows, I shall use that definition to provide an adequate explanation for Kuhn's description of scientific progress. To that end, we have to consider the following two questions:

(i) What is the content of the consensus of a scientific community?

(ii) How is normal science maintained, broken down, and re-established?

The answer of each of these two questions has two levels, the individual level and the social level, at which the explanation in terms of the precise definition of the concept of a paradigm works.

According to that definition, paradigms are exemplars that are generally accepted by the members of a scientific community. Thus, the answer to question (i) is that the consensus is an agreement on certain exemplars. Since these exemplars involve the other components of the disciplinary matrix (symbolic generalizations, models, and scientific values) as implicit moments, which become explicit when the exemplars perform their normative functions in normal science, the members of a scientific community are also committed to these components as a result of their commitment to the generally accepted exemplars. At the individual level, the student studies many exemplary problem solutions during his education, either in the class or in the laboratory, and he acquires and acknowledges the other components of the disciplinary matrix as a result of this study. At the social level, the generally accepted exemplary problem solutions guide and direct the research of the scientific community.

Regarding question (ii), the answer in terms of the precise definition of paradigms should be adequate to account for the three main aspects of the circular pattern of scientific development mentioned above. I have already discussed the explanation of aspect (i), concerning the persistence of normal science, in terms of exemplars at the end of the last chapter. In what follows, I consider the explanation of aspects (ii) and (iii).

According to the precise definition of paradigms, the exemplary problem solutions that are generally accepted by the members of a scientific community perform four normative functions in normal science: the semantic function, problem identification, solution assessment, and solution identification. These normative functions not only provide scientists with a sense of similarity and dissimilarity between different scientific problems but also with expectations, i.e., expectations that puzzles similar to the exemplary problems will be solved by solutions similar to the exemplary solutions. A failure of arriving at the expected acceptable solutions occurs at both the individual level and the social level. At the individual level, a scientist may fail to find the right solution and instead he generates anomalies. He may be blamed for his failure, e.g., he did not receive a good education or he did not train himself with a sufficient number of exemplary problem solutions. However, it might happen that sufficiently many scientists repeatedly fail to arrive at the expected acceptable solutions for certain problems. In this case, the current paradigm should be blamed, not the individual scientist. Scientists, in an increasing number, will doubt whether the acceptable solutions to the persistent anomalies should resemble the generally accepted exemplary solutions, and they will search for new kinds of theories and techniques. Thus, when the failure of arriving at the expected solutions reaches the social level, then the scientific community is in crisis and normal science breaks down.

Now it remains to show how the precise definition of paradigms may enable us to explain the re-establishment of normal science. We have seen how exemplars perform their normative functions in normal science by developing the skills of scientists to recognize the similarity relationships between different problems. However, in the period of a crisis, scientists typically search for solutions that are less similar to the generally accepted exemplars. In fact, Kuhn does allow the old paradigm to play a role in determining the new paradigm, the latter must resolve the anomalies of the former and reserve many of its successes, i.e., the new paradigm must involve some similarity to the old paradigm. Thus, the new paradigm is not entirely different from the old paradigm. When the majority of scientists accept the new paradigm, then they will no longer consider the similarity to the old exemplars as a criterion for the acceptability of proposed puzzle-solutions. Instead, the similarity to the new rather different exemplars will become the criterion by which proposed puzzle-solutions are judged. That transformation of criteria occurs at both the individual level and the social level, and when that happens, a new period of normal science is established.

It should be noted that it is not the individual scientist who has the similarity and dissimilarity relationships at his disposal. Instead, these relationships are properties or attributes of a specific scientific community, and an individual scientist has access to them only when he becomes a member in that community. In order to belong to a given scientific community, an individual must master the same similarity relationships as the other members of the community.

# Conclusion

The defects of scientific methods and of the traditional view of the history of science in providing an accurate image of science motivated Kuhn to develop his ideas in his book *The Structure of Scientific Revolutions*. In this book, Kuhn proposed that the philosopher of science should not aim to articulate a scientific method; instead, his concern should be the description and explanation of the process by which scientific knowledge is produced. Kuhn's concept of paradigm plays a central role in describing and explaining scientific development. In Chapter 1 of this thesis, the circular pattern of Kuhn's image of scientific progress is outlined. The period of pre-paradigm science ends when the proponents of a candidate paradigm make a significant and unprecedented achievement that attracts scientists away from other competing paradigms. Then, a period of normal science, characterized by the domination of a single paradigm, begins. The increasing number of serious anomalies, to which normal science ultimately leads, inaugurates a scientific revolution. A number of competing paradigms characterizes the period of a scientific revolution. The members of a scientific community will ultimately agree on one paradigm, and then, a new period of normal science begins. The development of science circulates in this manner.

In Chapter 2, the main criticisms raised against Kuhn's initial account of scientific development are discussed. Some critics found that Kuhn's use of the concept of paradigm involves serious ambiguity. Others found that Kuhn's notion of paradigm shift implies irrationality and relativism in science. Moreover, we found four historical cases—the discovery of the structure of DNA, Einstein's theory of general relativity, the theory of matter, and the development of the science of botany—that do not fit Kuhn's description of scientific progress.

In Chapter 3, Kuhn's responses to his critics are considered. Kuhn denied the charge of irrationality by suggesting that there are good reasons to which a scientist involved in a theory-choice situation can appeal. These reasons do not act as a proof; instead, they act as values. Kuhn also denied the charge of relativism by arguing that his view of scientific progress is essentially evolutionary. He admitted that his use of the concept of a paradigm in his book *The Structure of Scientific Revolutions* is ambiguous. Thus, he clarified the concept by making a distinction between two senses of paradigms: the disciplinary matrix and exemplary problem solutions. Kuhn identified four elements of the disciplinary matrix: symbolic generalizations, models, values, and exemplary problem solutions. However, Hoyningen-Huene found that taking the components of the disciplinary matrix to be inseparable moments of a single unity is more accurate than taking them to be separable and independent elements. In this manner, we arrive at a precise definition of paradigms. Paradigms are exemplary problem solutions that are generally accepted by the members of a scientific community, and they involve the other components of the disciplinary matrix, to which the members of a scientific community are committed, as implicit moments. These implicit moments become explicit when exemplary problem solutions perform their four normative functions—the semantic function, problem identification, solution assessment, and solution identification—in normal science. In Chapter 4, this definition is used to provide an adequate explanation of Kuhn's description of scientific development. This explanation accounts for the three main aspects of the circular pattern of the development of a scientific discipline: the persistence of normal science, the break-down of normal science, and the re-establishment of normal science. We noticed that the explanation works at both the individual level and the social level.