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"What Are Scientific Revolutions?" [1]

Thomas S. Kuhn

"What Are Scientific Revolutions?" attempts to refine and clarify the distinction between normal and revolutionary scientific *development. After an introductory presentation of the issue most of the chapter is devoted to the presentation of . . . the transition from an Aristotelian to a Newtonian understanding of motion . . . A concluding section epitomizes three features common to the examples. All are locally holistic in that they require a number of interrelated changes of theory to be made at once; only at the price of incoherence could these changes have occurred one step at a time. All require changes in the way some set of inter-defined scientific terms attached to nature, in the taxonomy provided by scientific language itself. And all also involved changes in something very like metaphor, in the scientist's acquired sense of what objects or events are like each other and of which differ". {original editors' intro}*

It is now almost twenty years since I first distinguished what I took to be two types of scientific development, normal and revolutionary.' Most successful scientific research results in change of the first sort, and its nature is well captured by a standard image: normal science is what produces the bricks that scientific research is forever adding to the growing stockpile of scientific knowledge. That cumulative conception of scientific development is familiar, and it has guided the elaboration of a considerable methodological literature. Both it and its methodological by-products apply to a great

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deal of significant scientific work. But scientific development also displays a non-cumulative mode, and the episodes that exhibit it provide unique clues to a central aspect of scientific knowledge. Returning to a long-standing concern, I shall therefore here attempt to isolate several such clues, first by describing three examples of revolutionary change and then by briefly discussing three characteristics which they all share. Doubtless revolutionary changes share other characteristics as well, but these three provide a sufficient basis for the more theoretical analyses on which I am currently engaged, and on which I shall be drawing somewhat cryptically when concluding this paper.

Before turning to a first extended example, let me try—for those not previously familiar with my vocabulary—to suggest what it is an example of. Revolutionary change is defined in part by its difference from normal change, and normal change is, as already indicated, the sort that results in growth, accretion, cumulative addition to what was known before. Scientific laws, for example, are usually products of this normal process: Boyle's law will illustrate what is involved. Its discoverers had previously possessed the concepts of gas pressure and volume as well as the instruments required to determine their magnitudes. The discovery that, for a given gas sample, the product of pressure and volume was a constant at constant temperature simply added to the knowledge of the way these antecedently understood[2] variables behave. The overwhelming majority of scientific advance is of this normal cumulative sort, but I shall not multiply examples.

Revolutionary changes are different and far more problematic. They involve discoveries that cannot be accommodated within the concepts in use before they were made. In order to make or to assimilate such a discovery one must alter the way one thinks about and describes some range of natural phenomena. The discovery (in cases like these "invention" may be a better word) of Newton's Second Law of motion is of this sort. The concepts of force and mass deployed in that law differed from those in use before the law was introduced, and the law itself was essential to their definition. A second, fuller, but more simplistic example is provided by the transition from Ptolemaic to Copernican astronomy. Before it occurred, the sun and moon were planets, the earth was not. After it, the earth was a planet, like Mars and Jupiter; the sun was a star; and the moon was a new sort of body, a satellite. Changes of that sort were not simply corrections of individual mistakes embedded in the Ptolemaic system. Like the transition to Newton's Laws of motion, they involved not only changes in Laws of nature but also changes in the criteria by which some terms in those laws attached to nature. These criteria, furthermore, were in part dependent upon the theory with which they were introduced.

When referential changes of this sort accompany change of law or theory, scientific development cannot be quite cumulative. One cannot get from the old to the new simply by an addition to what was already known. Nor can one quite describe the new in the vocabulary of the old or vice versa. Consider the compound sentence, "In the Ptolemaic system planets revolve about the earth; in the Copernican they revolve about the sun." Strictly construed, that sentence is incoherent. The first occurrence of the term "planet" is Ptolemaic, the second Copernican, and the two attach to nature differently. For no univocal reading of the term "planet" is the compound sentence true.

No example so schematic can more than hint at what is involved in revolutionary change. I therefore turn at once to some fuller examples, beginning with the one that, a generation ago, introduced me to revolutionary change, the transition from Aristotelian to Newtonian physics. Only a small part of it, centering on problems of motion and mechanics, can be considered here, and even about it I shall be schematic. In addition, my account will invert historical order and describe, not what Aristotelian natural philosophers required to reach Newtonian concepts, but what I, raised a Newtonian, required to reach those of Aristotelian natural philosophy. The route I traveled backward with the aid of written texts was, I shall simply assert, nearly enough the same one that earlier scientists had traveled forward with no text but nature to guide them.

I first read some of Aristotle's physical writings in the summer of 1947, at which time I was a graduate student of physics trying to prepare a case study on the development of mechanics for a course in science for nonscientists. Not surprisingly, I approached Aristotle's texts with the Newtonian mechanics I had previously read clearly in mind. The question I hoped to answer was how much mechanics Aristotle had known, how much he had left for people like Galileo and Newton to discover. Given that formulation, I rapidly discovered that Aristotle had known almost no mechanics at all. Everything was left for his successors, mostly those of the sixteenth and seventeenth centuries. That conclusion was standard, and it might in principle have been right. But I found it bothersome because, as I was reading him, Aristotle appeared not only ignorant of mechanics, but a dreadfully bad physical scientist as well. About motion, in particular, his writings seemed to me full of egregious errors, both of logic and of observation.

These conclusions were unlikely. Aristotle, after all, had been the much admired codifier of ancient logic. For almost two millennia after his death, his work played the same role in logic that Euclid's played in geometry. In addition, Aristotle had often proved an extraordinarily acute naturalistic observer. In biology, especially, his descriptive writings provided models that were central in the sixteenth and seventeenth centuries to the emergence of the modern biological tradition. How could his characteristic talents have deserted him so systematically when he turned to the study of motion and mechanics? Equally, if his talents had so deserted him, why had his writings in physics been taken so seriously for so many centuries after his death? Those questions troubled me. I could easily believe that Aristotle had stumbled, but not that, on entering physics, be had totally collapsed. Might not the fault be mine rather than Aristotle's, I asked myself. Perhaps his words had not always meant to him and his contemporaries quite what they meant to me and mine.

Feeling that way, I continued to puzzle over the text, and my suspicions ultimately proved well-founded. I was sitting at my desk with the text of Aristotle's *Physics* open in front of me and with a four-colored pencil in my hand. Looking up, I gazed

abstractedly out the window of my room—the visual image is one I still retain. Suddenly the fragments in my head sorted themselves out in a new way, and fell into place together. My jaw dropped, for all at once Aristotle seemed a very good physicist indeed, but of a sort I'd never dreamed possible. Now I could understand why he had said what he'd said, and what his authority had been. Statements that had previously seemed egregious mistakes, now seemed at worst near misses within a powerful and generally successful tradition. That sort of .experience—the pieces suddenly sorting themselves out and coming together in a new way—is the first general characteristic of revolutionary change that I shall be singling out after further consideration of examples. Though scientific revolutions leave much piecemeal mopping up to do, the central change cannot be experienced piecemeal, one step at a time. Instead, it involves some relatively sudden and unstructured transformation in which some part of the flux of experience sorts itself out differently and displays patterns that were not visible before.
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To make all this more concrete let me now illustrate some of what was involved in my discovery of a way of reading Aristotelian physics, one that made the texts make sense. A first illustration will be familiar to many. When the term “motion” occurs in Aristotelian physics, it refers to change in general, not just to the change of position of a physical body. Change of position, the exclusive subject of mechanics for Galileo and Newton, is one of a number of subcategories' of motion for Aristotle. Others include growth (the transformation of an acorn to an oak), alterations of intensity (the heating of an iron bar), and a number of more general qualitative changes (the transition from sickness to health). As a result, though Aristotle recognizes that the various subcategories are not alike in *all* respects, the basic characteristics relevant to the recognition and analysis of motion must apply to changes of all sorts. In some sense that is not merely metaphorical; all varieties of change are seen as like each other, as constituting a single natural family.[3]

A second aspect of Aristotle's physics—harder to recognize and even more important—is the centrality of qualities to its conceptual structure. By that I do not mean simply that it aims to explain quality and change of quality, for other sorts of physics have done that. Rather I have in mind that Aristotelian physics inverts the ontological hierarchy of matter and quality that has been standard since the middle of the seventeenth century. In Newtonian physics a body is constituted of particles of matter, and its qualities are a consequence of the way those particles are arranged, move, and interact. In Aristotle's physics, on the other hand, matter is very nearly dispensable. It is a neutral substrate, present wherever a body could be—which means wherever there's space or place. A particular body, a substance, exists in whatever place this neutral substrate, a sort of sponge, is sufficiently impregnated with qualities like heat, wetness, color, and so on to give it individual identity. Change occurs by changing qualities, not matter, by removing some qualities from some given matter and replacing them with others. There are even some implicit conservation laws that the qualities must apparently obey.[4]

Aristotle's physics displays other similarly general aspects, some of great importance. But I shall work toward the points that concern me from these two, picking up one other well—known one in passing. What I want now to begin to suggest is that, as one recognizes these and other aspects of Aristotle's viewpoint, they begin to fit together, to lend each other mutual support, and thus to make a sort of sense collectively that they individually lack. In my original experience of breaking into Aristotle's text, the new pieces I have been describing and the sense of their coherent fit actually emerged together.

Begin from the notion of a qualitative physics that has just been sketched. When one analyzes a particular object by specifying the qualities that have been imposed on omnipresent neutral matter, one of the qualities that must be specified is the object's position, or, in Aristotle's terminology, its place. Position is thus, like wetness or hotness, a quality of the object, one that changes as the object moves or is moved. Local motion (motion *tout court* in Newton's sense) is therefore change-of-quality or change-of-state for Aristotle, rather than being itself a state as it is for Newton. But it is precisely seeing motion as change-of-quality that permits its assimilation to all other sorts of change—acorn to oak or sickness to health, for examples. That assimilation is the aspect of Aristotle's physics from which I began, and I could equally well have traveled the route in the other direction. The conception of motion-as-change and the conception of a qualitative physics prove deeply interdependent, almost equivalent notions, and that is a first example of the fitting or the locking together of parts.

If that much is clear, however, then another aspect of Aristotle's physics—one that regularly seems ridiculous in isolation—begins to make sense as well. Most changes of quality, especially in the organic realm, are asymmetric, at least when left to themselves. An acorn naturally develops into an oak, not vice versa. A sick man often grows healthy by himself, but an external agent is needed, or believed to be needed, to make him sick. One set of qualities, one end point of change, represents a body's natural state, the one that it realizes voluntarily and thereafter rests. The same asymmetry should be characteristic of local motion, change of position, and indeed it is. The quality that a stone or other heavy body strives to realize is position at the center of the universe; the natural position of fire is at the periphery. That is why stones fall toward the center until blocked by an obstacle and why fire flies to the heavens. They are realizing their natural properties just as the acorn does through its growth. Another initially strange part of Aristotelian doctrine begins to fall into place.

One could continue for some time in this manner, locking individual bits of Aristotelian physics into place in the whole. But I shall instead conclude this first example with a last illustration, Aristotle's doctrine about the vacuum or void. It displays with particular clarity the way in which a number of theses that appear arbitrary in isolation lend each other mutual authority and support. Aristotle states that a void is impossible: his underlying position is that the notion itself is incoherent. By now it should be apparent how that might be so. If position is a quality, and if qualities cannot exist separate from matter, then there must be matter wherever there's position, wherever body might be. But that is to say that there must be matter everywhere in space: the void, space without matter, acquires the status of, say, a square circle.[5]

That argument has force. but its premise seems arbitrary. Aristotle need not, one supposes, have conceived position as a quality. Perhaps, but we have already noted that that conception underlies his view of motion as change-of-state, and other aspects of his physics depend on it as well. If there could be a void, then the Aristotelian universe or cosmos could. not be finite. It is just because matter and space are coextensive that space can end where matter ends, at the outermost sphere beyond which there is nothing at all, neither space nor matter. That doctrine, too, may seem dispensable. But expanding the stellar sphere to infinity would make problems for astronomy, since that sphere's rotations carry the stars about the earth. Another, more central, difficulty arises earlier. In an infinite universe there is no center—any point is as much the center as any other—and there is thus no natural position at which stones and other heavy bodies realize their natural quality. Or, to put the point in another way, one that Aristotle actually uses, in a void a body could not be aware of the location of its natural place. It is just by being in contact with all positions in the universe through a chain of intervening matter that a body is able to find its way to the place where its natural qualities are fully realized. The presence of matter is what provides space with structure.[6] Thus, both Aristotle's theory of natural local motion and ancient geocentric astronomy are threatened by an attack on Aristotle's doctrine of the void. There is no way to 'correct'' Aristotle's views about the void without reconstructing much of the rest of his physics.

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I shall conclude this discussion by asking what characteristics of revolutionary change are displayed by the examples at hand. Answers will fall under three headings, and I shall be relatively brief about each. The extended discussion they require, I am not quite ready to provide.

A first set of shared characteristics was mentioned near the start of this paper. Revolutionary changes are somehow holistic. They cannot, that is, be made piece-meal, one step at a time, and they thus contrast with normal or cumulative changes like, for example, the discovery of Boyle's law. In normal change, one simply revises or adds a single generalization, all others remaining the same. In revolutionary change one must either live with incoherence or else revise a number of interrelated generalizations together. If these same changes were introduced one at a time, there would be no intermediate resting place. Only the initial and final sets of generalizations provide a coherent account of nature. [. . . In] the case of Aristotelian physics, one cannot simply discover that a vacuum is possible or that motion is a state, not a change-of-state. An integrated picture of several aspects of nature has to be changed at the same time.

A second characteristic of these examples is closely related. It is the one I have in the past described as meaning change and which I have here been describing, somewhat more specifically, as change in the way words and phrases attach to nature, change in the way their referents arc determined. Even that version is, however, somewhat too general. As recent studies of reference have emphasized, anything one knows about the referents of a term may be of use in attaching that term to nature. A newly discovered property of electricity, of radiation, or of the effects of force on motion may thereafter be called upon (usually with others) to determine the presence of electricity, radiation, or force and thus to pick out the referents of the corresponding term. Such discoveries need not be and usually are not revolutionary. Normal science, too, alters the way in which terms attach to nature. What characterizes revolutions is not, therefore, simply change in the way referents arc determined but change of a still more restricted sort.

I low best to characterize that restricted sort of change is among the problems . that currently occupy me, and I have no full solution. But roughly speaking, the distinctive character of revolutionary change in language is that it alters not only the criteria by which terms attach to nature but also, massively, the set of objects or situations to which those terms attach. What had been paradigmatic examples of motion for Aristotle—acorn to oak or sickness to health—were not motions at all for Newton. In the transition, a natural family ceased to be natural; its members were redistributed among preexisting sets; and only one of them continued to bear the old name. [. . .]

What characterizes revolutions is, thus, change in several of the taxonomic categories prerequisite to scientific descriptions and generalizations. That change, furthermore, is an adjustment not only of criteria relevant to categorization, but also of the way in which given objects and situations are distributed among preexisting categories. Since such redistribution always involves more than one category and since those categories are inter-defined, this sort of alteration is necessarily holistic. That holism, furthermore, is rooted in the nature of language, for the criteria relevant to categorization are *ipso facto* the criteria that attach the names of those categories to the world. Language is a coinage with two faces, one looking outward to the world, the other inward to the world's reflection in the referential structure of the language.

Look now at the last of the three characteristics shared by my three examples. It has been the most difficult of the three for me to see, but now seems the most obvious and probably the most consequential. Even more than the others, it should repay further exploration. All of my examples have involved a central change of model, metaphor, or analogy—a change in one's sense of what is similar to what, and of what is different. Sometimes, as in the Aristotle example, the similarity is internal to the subject matter. Thus, for Aristotelians, motion was a special case of change, so that the falling stone was *like* the growing oak, or *like* the person recovering from illness. That is the pattern of similarities that constitutes these phenomena a natural family, that places them in the same taxonomic category, and that had to be replaced in the development of Newtonian physics. Elsewhere the similarity is external.

All these cases display interrelated features familiar to students of metaphor. In each case two objects or situations are juxtaposed and said to be the same or similar. (An even slightly more extended discussion would have also to consider examples of dissimilarity, for they, too, are often important in establishing a taxonomy.) Furthermore, whatever their origin—a separate issue with which I am not presently concerned—the primary function of all these juxtapositions is to transmit and maintain a taxonomy. The juxtaposed items are exhibited to a previously uninitiated audience by someone who can already recognize their similarity, and who urges that audience to learn to do the same. If the exhibit succeeds, the new initiates emerge with an acquired list of features salient to the required similarity relation— with a feature-space, that is, within which the previously juxtaposed items are durably clustered together as examples of the same thing and are simultaneously separated from objects or situations with which they might otherwise have been, confused. Thus, the education of an Aristotelian associates the flight of an arrow with a falling stone and both with the growth of an oak and the return to health. All are thereafter changes of state; their end points and the elapsed time of transition are their salient features. Seen in that way, motion cannot be relative and must be in a category distinct from rest, which is a state. Similarly, on that view, an infinite motion , because it lacks an end point, becomes a contradiction in terms.

The metaphor-like juxtapositions that change at times of scientific revolution are thus central to the process by which scientific and other language is acquired. Only after that acquisition or learning process has passed a certain point can the practice of science even begin. Scientific practice always involves the production and the explanation of generalizations about nature; those activities presuppose a language with some minimal richness; and the acquisition of such a language brings knowledge of nature with it. When the exhibit of examples is part of the process of learning terms like “motion,” ‘‘cell,‘‘ or ‘‘energy element,’’ what is acquired is knowledge of language and of the world together. On the one hand, the student learns what these terms mean, what features are relevant to attaching them to mature, what things cannot be said of them on pain of self-contradiction, and so on. On the other hand, the student learns what categories of things populate the world, what their salient features arc, and something about the behavior that is and is not permitted to them. In much of language learning these two sorts of knowledge—knowledge of words and knowledge of nature—are acquired together, not really two sorts of knowledge at all, but two faces of the single coinage that a language provides.

The reappearance of the double-faced character of scientific language provides an appropriate terminus for this paper. If I am right, the central characteristic of scientific revolutions is that they alter the knowledge of nature that is intrinsic to the language itself and that is thus prior to anything quite describable as description or generalization, scientific or everyday. To make the void or an infinite linear motion part of science required observation reports that could only be formulated by altering the language with which nature was described. Until those changes had occurred, language itself resisted the invention and introduction of the sought after new theories. The same resistance by language is, I take it, the reason for Planck's switch from ''element'' and ''resonator'' to ''quantum'' and ''oscillator.'' Violation or distortion of a previously unproblematic scientific language is the touchstone for revolutionary change.

Notes

1. Thomas S. Kuhn, *The Structure of Scientific Revolutions,* 2nd ed., rev. (Chicago: University of Clicago Press, 1969). The book was first published in 1962.
2. The phrase "antecedently understood" was introduced by C. G. Hempel, who shows that it will serve many of the same purposes as "observational" in discussions involving the distinc-tion between observational and theoretical terms (cf., particularly, his *Aspects of Scientific Explanation* (New York: Free Press, 1965), pp. 208ff.). I borrow the phrase because the notion of an antecedently understood term is intrinsically developmental or historical, and its use within logical empiricism points to important areas of overlap between that traditional approach to philosophy of science and the more recent historical approach. In particular, the often elegant apparatus developed by logical empiricists for discussions of concept formation and of the definition of theoretical terms can be transferred as a whole to the historical approach and used to analyze the formation of new concepts and the definition of new terms both of which usually

take place in intimate association with the introduction of a new theory. A more systematic way of preserving an important part of the observation/theoretical distinction by embedding it in a developmental approach has been developed by Joseph D. Sneed *(The Logical Struct ure of A Mathematical Physics (* Do rd recht *: R ei* del, t *9 7* t), t p . t 6—1. , 249—307). Wolfgang Stegmuller has clarified and extended Sneed's approach by positing a hierarchy of theoretical terms, each level introduced within a particular historical theory *(The Structure and Dynamics of Theories* (New York: Springer, 1976), pp. 40—67, 196—231). The resulting picture of linguistic strata shows intriguing parallels to the one discussed by Michel Foucault in *The Archeology of Knowledge,* trans. A. M. Sheridan Smith (New York: Pantheon, 1972).

3. For all of this see Aristotle's *Physics,* Book V, Chapters 1—2 (224a21—226b16). Note that, . Aristotle does have a concept of change that is broader than that of motion. Motion is change of substance, change from something to something (225a 1). But change also includes coming to be and passing away, i.e., change from nothing to something and from something to nothing (225a34—225b9), and these are not motions.
4. Compare Aristotle's *Physics,* Book 1, and especially his *On Generation and Corruption,* Book 11, Chapters 1—4.
5. There is an ingredient missing from my sketch of this argument: Aristotle's doctrine of place, developed in the *Physics,* Book IV, just before his discussion of the vacuum. Place, for Aristotle, is always the place of body or, more precisely, the interior surface of the containing or surrounding body (212a2—7). Turning to his next topic, Aristotle says, "Since the void (if there is any) must be conceived as place in which there might be body but is not, it is clear that, so conceived the void cannot exist at all, either as inseparable or separable" (214a 16—20). (1 quote from the Loeb Classical Library translation by Philip 11. Wickstead and Francis M. Cornford, a version that, on this difficult aspect of the *Physics,* seems to me clearer than most, . both in text and commentary.) That it is not merely a mistake to substitute "position" for "place" in a sketch of the argument is indicated by the last part of the next paragraph of my text.
6. For this and closely related arguments see Aristotle, *Physics,* Book IV, Chapter 8 (especially 214b27—2 I 5a24).
7. Alessandro Volta, "On the Electricity Excited by the mere Contact of Conducting Substances of Different Kinds," *Philosophical Transactions,* 90(1800), 403—431. On this subject see, T. M. Brown, "The Electric Current in Early Nineteenth-Century French Physics," *Historical Studies in the Physical Sciences,* 1(1969), 61—103.
8. The illustrations are from A. de Ia Rive, *Traite d'electricite theorique et appliquee,* Vol. 2 (Paris: J. B. Bailiere, 1856), pp. 600, 656. Structurally similar but schematic diagrams appear in Faraday's experimental researches from the early 1830s. My choice of the 1840s as the period when such diagrams became

standard results from a casual survey of electricity texts hying ready to hand. A more systematic study would, in any case, have had to distinguish between British, French, and German responses to the chemical theory of the battery.

9. For the full version with supporting evidence see my *Black-Body Theory and the Quantum Discontinuity. 1894—1912* (Oxford and New York: Clarendon and Oxford University Presses, 1978).