Chapter 16
Abgesang on Kuhn's "Revolutions"
Ursula Klein

No other theory has caused more turbulence in the history and philosophy of science as Thomas S. Kuhn's theory of scientific revolutions. What has become of this theory around half a century after its publication? What does recent historiography of science have to say about Kuhn's concept of scientific revolution? After a brief overview of Kuhn's theory, I discuss distinct aspects of it, including the concepts of "structure" and "revolution."

According to Kuhn, the development of the natural sciences does not follow a linear course. It is not a continuous, cumulative process in which new knowledge is simply added to the old, so that the stock of knowledge would permanently grow and become ever more validated and reliable. Rather, a look at the history of the sciences shows that long phases of cumulative knowledge production are followed by substantial restructuring processes, in which objects of inquiry previously believed to be especially important are called into question, scientific methods, values and ways of argumentation are partially discarded, and old theories are replaced by new ones. Kuhn calls these drastic changes "revolutions," drawing an explicit parallel between scientific and political or social revolutions (Kuhn 1970, 92–94). Scientific revolutions, accordingly, lead not only to profound breaks with existing scientific traditions, but also take place in a relatively short period of one or two generations, or more precisely, a span of no more than 20 to 40 years.

When Kuhn published his theory in 1962, he was met with vehement criticism from philosophers of science. As is well known, most Anglo-Saxon philosophers of science during this time took a normative, strongly idealized view of scientific rationality, which clashed with Kuhn's understanding of how scientists accept scientific innovations. Kuhn argued that the acceptance of revolutions always presupposes scientists' willingness to change their perspective. The willingness to accept a new theory along with new research objects, methods, ways of argumentation and standards of evaluation, he pointed out, is attained less through rational judgment than through familiarization with new views in the context of scientific education. As this argument challenged the philosophical ideal of rationality, it does not come as a surprise that analytical philosophers' counterreaction was correspondingly emphatic.

The historians of science of the 1960s and 1970s were considerably more welcoming to Kuhn's theory. The argument that the long history of the sciences included repeated revolutionary cataclysms was by no means a novelty for them. The episodes of scientific change linked with "great scientists" such as Copernicus, Galileo, Newton, Lavoisier, Darwin, Planck or Einstein had been designated as revolutions long before Kuhn. To name just a few examples: in 1773 the French chemist Antoine-Laurent Lavoisier claimed that his research would trigger a "revolution" in chemistry. Charles Darwin stated in 1859 that Charles Lyell had started a "revolution" in geology, and that he himself would cause a "revolution" in natural history.[1] For the leading historians of science of the 1950s, revolutionary breaks were among the topics of high interest. The French historian Alexandre Koyré wrote in 1943 that the conceptual changes in the sciences of the late sixteenth and seventeenth centuries represented "the most profound revolution achieved or suffered by the human mind" since antiquity. Several years later, the English historian Herbert Butterfield claimed that the Scientific Revolution of the seventeenth century "outshines everything since the rise of Christianity and reduces the Renaissance and Reformation to the rank of mere episodes [...] [It is] the real origin both of the modern world and of the modern mentality."[2] In 1961, the American historian of science Henry Guerlac described the Chemical Revolution in the final third of the eighteenth century in similar words. Lavoisier had "refashioned the materials, the concepts, and even the language of chemistry so radically," he claimed, that "the science as we know it today seems almost to have been born with him" (Guerlac 1961, XIV).

Kuhn adopted this perspective from professional historians of science and aimed to further develop it theoretically. The very title of his major book, *The Structure of Scientific Revolutions* (my emphasis), indicates that he aspired to more than just the affirmation of a known argument in the history of science. But why "structure"?

"Structure"

Kuhn did not only advance the thesis that radical change had taken place repeatedly in the history of the sciences—he also developed more precise ideas about the *what* and *how* of these processes. Concerning the latter, he argued that scientific developments always take place according to the same scheme

[1] See Cohen (1985, 4).
[2] Quoted after Shapin (1996, 1–2).

or pattern, in other words they exhibit a universal structure.[3] His model of the structure of the long-term development of the sciences is well known and strikingly simple. It can be summarized as follows:

Normal science A1 → anomaly → crisis → revolution → normal science A2.

According to Kuhn, "normal science" constitutes the longest phase of development in any particular science. During this phase, empirical knowledge is expanded, and theories, instruments and methods are elaborated and refined, yielding an accumulation of knowledge. An unexpected discovery, however, constitutes an "anomaly," which is typically followed by a "crisis," wherein scientists encounter serious obstacles in attempts to integrate the discovery into the existing system of knowledge. And a "crisis" generally leads to a "scientific revolution," which results in a new form of the normal science at stake.[4]

Clearly, with respect to the long-term development of a science, the meaning of "structure" is well defined here. Suffice to add that this concept implies a thoroughly internalist understanding of scientific change in history. While Kuhn conceded that social factors could exert a certain influence on the development of sciences, he believed that their impact was so marginal that it could be disregarded in his construction of a historical theory.[5] Less simple, however, is the question of what "structure" means with respect to the revolutionary event itself.

Social and political revolutions affect the power structure of a society and the institutions that protect and perpetuate it. Parallel to this, one might first ask what, according to Kuhn, is the central objective of a scientific revolution? In *Structure*, Kuhn answers this question with his concept of paradigm. In all scientific revolutions, a new paradigm replaces an already existing one. As has been repeatedly shown, Kuhn's concept of paradigm is not precisely defined. Its core element is a scientific theory, but Kuhn also argues that additional elements are included, some of which remain unarticulated and are learned only during the process of scientific socialization.[6] Scientists always orient their teaching and research on

---

[3] On this see also Hoyningen-Huene (1989, 34–37).

[4] In the first edition of his book, Kuhn observed: "all crises close with the emergence of a new candidate for paradigm"; Kuhn (1962, 84). In other words, he claimed that crises are always resolved by a revolution. In the second edition published in 1970, by contrast, he allows three possibilities for terminating a crisis: the normal science can ultimately find a way to integrate the anomaly; the anomaly can be declared irresolvable for the time being and its solution postponed; or a new paradigm can be introduced in the context of a revolution; Kuhn (Kuhn 1970, 84).

[5] Of the Copernican Revolution, for instance, he writes that it was also triggered by "the social pressure for calendar reform." Yet he immediately adds that issues of this kind were "out of bounds" for his essay, which can only mean that he felt justified in neglecting them in his theory; Kuhn (1970, 69).

[6] For further details see Hoyningen-Huene (1989, 133–143).

a set of rules, values, standards and know-how, which are difficult to disentangle and are taken as given within a scientific community. According to Kuhn, this orientation knowledge and set of rules is an important part of a paradigm, which is also affected in a scientific revolution.

Let us now address the *how* question along with the meaning of "structure" with respect to the revolutionary event itself. As Kuhn defined scientific theory as the core element of a paradigm, it would be consistent to argue that the major event in a scientific revolution is the introduction of a new scientific theory. Approaches to new theories, Kuhn observes, are already worked out during a "crisis" and subjected to controversial discussion, but it is not until the phase of the revolution that the decisive step is taken toward elaborating a new theory. How does this happen?

At this critical point of his theory, Kuhn turns to psychology. Answering the question of how a new theory is formulated, he points out, "demand[s] the competence of a psychologist even more than that of the historian" (Kuhn 1970, 86). This does not prevent him from seeking his own answer. Having discussed previous borrowings from Gestalt psychology (1970, 85), he first reminds his readers that the scientists themselves "often speak of the 'scales falling from the eyes' or of the 'lighting flash' that 'inundates' a previously obscure puzzle." "On other occasion," he continues, "the relevant illumination comes in sleep," to further state that it is "flashes of intuition through which a new paradigm is born" (1970, 122f.). The most revealing and astonishing formulation, however, is the following: Crises, Kuhn states, "are terminated, not by deliberation and interpretation, but by a relatively sudden and unstructured event like the gestalt switch." (1970, 122, my emphasis).

Was it not Kuhn's own intention to explain to us the "structure" of scientific revolutions? Alas, his theory ends with explaining the construction of a new theory as a mental event *sui generis*, which allows neither conceptual analysis nor displays structural features. With this approach, Kuhn comes dangerously close to both the analytical philosophy of science, of which he was otherwise so critical, and to the traditional historiography of science. Clearly, only individuals have "flashes of intuition." When it comes to explaining theoretical novelty in the history of sciences, what counts, according to Kuhn, are not explorative work by means of communal theoretical tools, but the individual intuitions of the great men of science.[7]

Let us now turn to some additional aspects of Kuhn's concept of scientific revolutions, beginning with the relation between continuity and discontinuity. What and how much, in Kuhn's view, remains preserved in a scientific revolution—and, regarded from a broader perspective, flows into a continuous trajec-

[7] On theoretical tools of scientific communities, see Kaiser (2005); Klein (2003).

tory of scientific change over time? And how much is discarded? There are many formulations in Kuhn's *Structure* that suggest he understood a scientific revolution to be a radical fissure in an existing scientific practice, or a break from an existing tradition. This is also indicated by his discussion of scientific revolutions as "changes of world view." "It is rather as if the professional community had been suddenly transported to another planet where familiar objects are seen in a different light and are joined by unfamiliar ones as well," Kuhn drastically states (1970, 111). On the other hand, his *Structure* also includes statements that allow the conclusion that in scientific revolutions large parts of knowledge and familiar practices remain intact. Kuhn never ventured so far as to argue that a break with a scientific tradition would affect the disciplinary boundaries themselves. For instance, he does not claim that Lavoisier's Chemical Revolution made all previous talk of "chemistry" obsolete, or that Einstein reinvented physics as a discipline.

In the final chapter of *Structure*, which bears the paradoxical title "Progress through Revolutions," Kuhn tackles a question that is intimately connected with the problem of continuity and discontinuity: what about our intuition about the progress of science? "Why is progress a perquisite reserved almost exclusively for the activities we call science?" Kuhn asks. "Why should the enterprise sketched above move steadily ahead in ways that, say, art, political theory, or philosophy do not?" (1970, 160). These are vexing questions for him that should no longer exist on the basis of the theory he outlined beforehand. Clearly, they served to fend off all-too radical consequences of his theory. Yet, their theoretical costs are just as unmistakable.

First, in the context of his considerations about progress in the history of science, Kuhn suddenly feels compelled to speak of a "continuing evolution" of the sciences (1970). Second, in the subsequent discussion about the issue, he comes to the general conclusion that scientific progress lies within a scientific community's capability to resolve problems across paradigm change. "The scientific community," he points out, "is a supremely efficient instrument for maximizing the number and precision of the problem solved through paradigm change." He further observes: "As a result, though new paradigms seldom ever possess all the capabilities of their predecessors, they usually preserve a great deal of the most concrete parts of scientific achievement and they always permit additional concrete problem-solutions besides" (1970, 169). This statement does not sound like the description of a revolutionary break from a tradition, or a sudden switch to a new world-view; rather, it highlights continuity. It raises another question—Had Kuhn not identified that what is recognized as a problem or an achievement as dependent on the paradigm of a scientific community? Kuhn fails to provide a compelling answer to this question.

In today's historiography of science, there is a broad consensus that scientific practice and the stocks of knowledge it produces are restructured again and again, and that such restructuring processes were, and still are, occasionally so profound that they yield new concepts, theories, methods, values, objects of research and sometimes even new research areas. Albert Einstein's theory of relativity revised the scope and truth claims of classical mechanics and electrodynamics, significantly shifting their importance for the overall discipline of physics; what was previously held to be absolutely true, basic knowledge now became special knowledge, valid only under specific framing conditions.[8] Darwin's theory of evolution fundamentally questioned the biological dogma of the constancy of species, and replaced it with a new view of the historical development of species. The chemistry of the eighteenth century used new concepts that were incompatible with alchemy, with the far-reaching consequence that many of the alchemists' questions were no longer considered to be legitimate objects of chemical research. Thus, from the perspective of history of science, Kuhn correctly pointed out that the historical change of the sciences entailed not only the accumulation of knowledge and the addition of new methods and standards to the existing ones, but that there are also processes of restructuring. However, apart from the problems discussed above, Kuhn's idea about the duration of scientific "revolutions" is highly questionable from the historians' perspective. As mentioned above, Kuhn's concept of scientific revolutions drew a parallel to social and political revolutions. Accordingly, scientific "revolutions" would take place within one or two generations, or in a maximum of twenty to forty years. On a timeline spanning several centuries, they would thus appear as punctuated events.

With regard to the so-called Copernican Revolution, historians of science have shown that there were doubts about Ptolemy's closed geocentric model of the cosmos long before Nicolaus Copernicus (1473–1543), and that it took another 100 years before Copernicus' heliocentric model was further developed by Johannes Kepler (1571–1630) into a modern model with elliptical planetary orbits, which further unified the different spheres of the universe.[9] Moreover, today many historians of science reject the more general assumption that a big Scientific Revolution took place in the seventeenth century. As numerous empirical studies have shown, shifts in the meanings of concepts, abstraction and mathematical representation and emphasis on experimentation had already begun in the late Middle Ages. Step by step, this created the prerequisites for the works of Copernicus, Galileo, Kepler and Newton. Upon in-depth historical research, what at first glance appears to be the exclusive revolutionary work of scientific titans like Galileo and Newton turns out to be the final, consequent step in a long

[8] See Renn (2006).

[9] See Boner (2013); Krafft (1997); Zinner 1988).

restructuring process, albeit a creative one that was certainly not taken by anyone.[10]

Likewise, the changes in chemistry in the final third of the eighteenth century, which went down in history as Lavoisier's Chemical Revolution, were the consequence of processes that lasted more than a century. The restructuring activities during the transition from pre-modern alchemy to early modern chemistry were so complex that there is still no agreement among historians of chemistry concerning the questions of which parts of alchemy/chemistry were involved and how to identify the beginning and end of these processes. The phenomenon of chemists shifting away from alchemistic philosophies of substances and transmutation, and turning towards the early modern conceptual system of chemical compound, composition, analysis and synthesis was a gradual process that had already begun in the final third of the seventeenth century. Around the mid-eighteenth century the majority of chemists were using the chemical concepts and analytical methods, which in Kuhn's day were attributed to Lavoisier. Their quantitative chemical analysis, for instance, presumed the conservation of mass and balanced the mass of the substance to be analyzed with the sum of the masses of its components. Yet for a long time these assumptions were considered a distinguishing feature of Lavoisier's chemistry.[11]

Similar to Galileo and Newton, Lavoisier, too, merely drew the decisive theoretical consequences from previous research results and existing problems. His replacement of phlogiston theory with the theory of oxygen and hydrogen, for instance, was doubtlessly a creative feat, yet it was based on numerous preparatory works by other chemists, and on the rigorous exploration of existing conceptual possibilities. Asking about the end of the restructuring processes in chemistry also raises difficulties. For instance, Lavoisier used a concept of chemical compounds that had already been introduced in the early eighteenth century and had long been used parallel to older conceptions about the generation and structure of substances. In this vein, "chemical affinity" was the main conceptual criterion for demarcating chemical compounds from mechanical mixtures of substances. The modern concept of a chemical compound, however, would also place the additional demand of constant proportions of the components. Yet this additional criterion was not introduced until decades later, around 1800, well after Lavoisier.

Similar considerations regarding the duration of restructuring processes are also valid for the so-called Darwinian revolution. Not only did Darwin build on the works of many botanists, zoologists and geologists, what is more, his theory was initially misunderstood as a teleological theory of development, according to which living beings constantly continue to perfect themselves and develop into

[10] See Damerow et al. (1992); Shapin (1996).
[11] See Klein (1994, 2015); Klein and Lefèvre (2007).

higher forms. The Darwinian theory of evolution as we know it was not accepted within the scientific community and thus could have hardly promoted a Darwinian revolution. Not until around 1930 was it perceived to be what it is, a theory that grants a constitutive role to accident, namely random mutations, in addition to selection by environmental factors, which determine the direction of evolution in tandem.[12]

All of these cases concern profound scientific changes, but these spanned considerably longer periods of time and involved significantly more scientists and generations of scientists than Kuhn postulates in his theory. The temporal boundaries of these processes, with the determination of a beginning and ending, always entail an arbitrary element, or something that is difficult to justify independent of the historians' interpretations and understanding. Should we opt, like Kuhn, to resort to analogies to social and political changes, the term "revolution" seems particularly unsuitable here. Political and social "revolutions" proceed swiftly, whereas most of the restructuring processes in the sciences proceed slowly and gradually, involving many generations of scientists.

What consequences do these considerations have for Kuhn's larger theory of scientific change in history, and for his concept of structure along with his phase model? Let us assume that Kuhn agreed with historians' objection to his concept of punctuated scientific revolutions. Assume he would accept that processes of restructuring in the sciences often span many generations or even centuries. His argument that the development of the sciences in history does not proceed only cumulatively and continuously, but also involves processes of restructuring and discarding, would then still be true. However, with this, the distinctive part of his theory, built around the concept of structure, would collapse. The assumption of gradual restructuring processes is incompatible with Kuhn's structural phase model, which clearly demarcates between normal science, anomaly, crisis and revolution. This is one reason why Kuhn's attempt to reveal a universal "structure" of scientific change in history has failed.

References

Boner, P. J. (2013). *Kepler's Cosmological Synthesis: Astrology, Mechnaism and the Soul*. Leiden; Boston: Brill.

Cohen, I. B. (1985). *Revolution in Science*. Cambridge; London: Harvard University Press.

Damerow, P., G. Freudenthal, P. McLaughlin, and J. Renn (1992). *Exploring the Limits of Preclassical Mechanics: A Study of Conceptual Development in Early Modern Science: Free Fall and Compounded Motion in the Work of Descartes, Galileo and Beeckman*. New York, Berlin, Heidelberg: Springer.

[12] See Lefèvre (2009).

Guerlac, H. (1961). *Lavoisier – The Crucial Year: The Background and Origin of His First Experiments on Combustion in 1772*. Ithaca, New York: Cornell University Press.

Hoyningen-Huene, P. (1989). *Die Wissenschaftsphilosophie Thomas S. Kuhns. Rekonstruktion und Grundlagenprobleme*. Braunschweig: Vieweg & Sohn. English translation by Alexander T. Levine, Reconstructing Scientific Revolutions. Thomas S. Kuhn's Philosophy of Science, Chicago, London: The University of Chicago Press, 1993.

Kaiser, D. (2005). *Drawing Theories Apart: The Dispersion of Feynman Diagrams in Postwar Physics*. Chicago; London: The University of Chicago Press.

Klein, U. (1994). *Verbindung und Affinität: die Grundlegung der modernen Chemie an der Wende des 17. zum 18. Jahrhundert*. Basel, Boston, Berlin: Birkhäuser.

— (2003). *Experiments, Models, Paper Tools. Stanford: Cultures of Organic Chemistry in the Nineteenth-Century*. Stanford: Stanford University Press.

— (2015). A Revolution that Never Happened. *Studies in the History and Philosophy of Science*. (in press).

Klein, U. and W. Lefèvre (2007). *Materials in Eighteenth-Century Science: A Historical Ontology*. Cambridge, Mass.: the MIT Press.

Krafft, F. (1997). Unverstandene Horaz-Zitate bei Nicolas Copernicus als Datierungsmittel. *Sudhoffs Archiv*(81):139–157.

Kuhn, T. S. (1962). *The Structure of Scientific Revolutions*. Chicago: The University of Chicago Press.

— (1970). *The Structure of Scientific Revolutions*. Second enlarged edition. Chicago: The University of Chicago Press.

Lefèvre, W. (2009). *Die Entstehung der biologischen Evolutionstheorie*. Frankfurt/Main: Suhrkamp.

Renn, J. (2006). *Auf den Schultern von Riesen und Zwergen: Einsteins unvollendete Revolution*. Weinheim: Wiley-VCH.

Shapin, S. (1996). *The Scientific Revolution*. Chicago: The University of Chicago Press.

Zinner, E. (1988). *Entstehung und Ausbreitung der Copernikanischen Lehre*. Munich: C. H. Beck.