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SCIENTIFIC EXPLANATION: CAUSATION *AND* UNIFICATION

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For the past few years I have been thinking about the philosophy of scientific explanation from the standpoint of its recent history. Many of these reflections have been published in *Four Decades of Scientific Explanation* (1990). They have, I believe, provided some new insight on some old problems, and they suggest that genuine progress has been made in this area of philosophy of science.

§ 1. *Looking Back: Two Grand Traditions*

The classic essay, "Studies in the Logic of Explanation," by Carl G. Hempel and Paul Oppenheim (1948) constitutes the fountainhead from which almost everything done subsequently on philosophical problems of scientific explanation flows. Strangely enough, it was almost totally ignored for a full decade. Although the crucial parts were reprinted in the famous anthology *Readings in the Philosophy of Science*, edited by Herbert Feigl and May Brodbeck (1953), it is not cited at all in R. B. Braithwaite's well-known book, *Scientific Explanation* (1953). During the first decade after publication of the Hempel-Oppenheim paper very little was published on scientific explanation in general—Braithwaite's book being the main exception. Most of the work on explanation during that period focused either on explanation in history or on teleological/functional explanation.

In the years 1957 and 1958 the situation changed dramatically. At that time a deluge of work on scientific explanation began, much of it highly critical of the Hempel-Oppenheim view. Vigorous attacks came from Michael Scriven and N. R. Hanson among others. Sylvain Bromberger and Israel Scheffler offered important criticisms, but they were offered more in the spirit of friendly amendments than outright attacks on the Hempel-Oppenheim program (see W. Salmon, 1990, pp. 33–46).

When we reflect on what happened we can see that two grand traditions emerged. Hempel advocated a view of scientific explanation according to which explanation consists in deductive or inductive subsumption of that which is to be explained (the explanandum) under one or more laws of nature. This tradition could find examples that had strong intuitive appeal—for instance, the explanation of the laws of optics by Maxwell's electrodynamics, or the explanation of the ideal gas law by the molecular-kinetic theory. These examples also illustrate what is often called "theoretical reduction" of one theory to another. Another example, if it could be worked out successfully, would be methodological individualism in the social sciences, for it would result in the reduction of the various social sciences to psychology.

Ironically, the very examples that furnish the strongest intuitive appeal for the subsumption approach are of a type that Hempel and Oppenheim found intractable. Although they offered an account of explanations of particular facts, they acknowledged in a notorious footnote (note 33), that they could *not* provide an account of explanations of general laws. To the best of my knowledge, Hempel never returned to this recalcitrant problem. It should also be noted that, while Hempel and Oppenheim casually identified their pattern of explanation (later known as the *deductive-nomological* or *D-N* model) with causal explanation, Hempel later argued emphatically that causality does not play any sort of crucial role in scientific explanation (1965, § 2.2).

The other major tradition was advanced primarily by Scriven, and it made a strong identification between causality and explanation. Roughly and briefly, to explain an event is to identify its cause. The examples that furnish the strongest intuitive basis for this conception are cases of explanations of particular occurrences—for instance, the sinking of the Titanic or the Chernobyl nuclear accident. The most serious problem with this approach has been the lack of any adequate analysis of causality on which to found it. Given Hume's searching critique of that concept, something more was needed.

As these two traditions developed over the years, there was often conflict, sometimes quite rancorous, between their advocates. At present, I believe, we have reached a stage in which a significant degree of rapprochement is entirely possible.

§ 2. *Explanation as Unification*

The idea that scientific explanation consists in showing that apparently disparate phenomena can be shown to be fundamentally similar has been around for a long time, long before 1948. However, Michael Friedman, in "Explanation and Scientific Understanding" (1974), seems to have been the first philosopher to articulate this conception clearly and to attempt to spell out the details. His basic thesis is that we increase our scientific understanding of the world to the extent that we can reduce the number of independently acceptable assumptions that are required to explain natural phenomena. By phenomena he means regularities in nature such as Kepler's first law (planets move in elliptical orbits) or Hooke's law (the amount of deformation of an elastic body is proportional to the force applied). It should be noted that Friedman is attempting to furnish an account of the explanation of laws, which is just the sort of explanation Hempel and Oppenheim found themselves unable to handle.

In order for Friedman's program to work, it is obviously necessary to be able to count the number of assumptions involved in any given explanation. In order to facilitate that procedure, Friedman offers a definition of a technical term, "K-atomic statement." This concept is relativized to a knowledge situation K. A statement is K-atomic provided it is not equivalent to two or more generalizations that are independently acceptable in knowledge situation K. A given statement is acceptable independently of another if it is possible to have evidence adequate for the acceptance of the given statement without *ipso facto* having evidence adequate to accept the other. The problem that arises for Friedman's program is that it seems impossible to have any K-atomic statements—at least, any that could plausibly be taken as fundamental laws of nature. For instance, Newton's law of universal gravitation, which prior to Einstein, was a good candidate for a fundamental law, can be partitioned into (1) "Between all pairs of masses in which both members are of astronomical dimensions there is a force of attraction proportional to the product of the masses and inversely proportional to the square of the distance between them," (2) "Between all pairs of masses in which one member is of astronomical dimensions and one is smaller there is a force of attraction...," and (3) "Between all pairs of masses in which both are of less than astronomic size there is a force of attraction..." Statement (1) is supported by planetary motions and the motion of the moon. Statement (2) is supported by Newton's falling apple, and indeed, by all phenomena to which Galileo's law of falling bodies applies. Statement (3) is supported by the Cavendish torsion-balance experiment. It seems possible to partition virtually any universal statement into two or more independently acceptable generalizations.

If Friedman's program had worked it would have solved the Hempel-Oppenheim problem of footnote 33. It appears, however, not to be satisfactory in the form originally given. Although Philip Kitcher (1976) offered his own (different) critique of Friedman's paper, he accepted the basic idea of explanation as unification, and he has elaborated it in a different way in a series of papers, of which "Explanatory Unification and the Causal Structure of the World" (1989) is the most recent and most detailed.

§ 3. *Causality and Mechanism*

Around 1970, when I was trying to work out the details of the *statistical relevance* or *S-R* model of scientific explanation, I had hopes that the fundamental causal concepts could be explicated in terms of statistical concepts alone, and that, consequently, the *S-R* model could furnish what was chiefly lacking in the causal approach. By 1980, that no longer seemed possible, and I shifted my focus to an attempt to explicate certain causal mechanisms, in particular, causal interactions and causal processes (see W. Salmon, 1984, chaps. 5–6). I took as primitives the notion of a process and that of a spatio-temporal intersection of processes. The aim is to distinguish between processes that are causal and those that are not (causal processes vs. pseudo-processes) and to distinguish those intersections of processes (whether causal or pseudo) that are genuine causal interactions and those that are not.

The basic idea—stated roughly and briefly—is that an intersection of two processes is a *causal interaction* if both processes are modified in the intersection in ways that persist beyond the point of intersection, even in the absence of further intersections. When two billiard balls collide, for instance, the state of motion of each is modified, and those modifications persist beyond the point of collision. A *process is causal* if it is capable of transmitting a mark—that is, if it is capable of entering into a causal interaction. For example, a beam of white light becomes and remains red if it passes through a piece of red glass, and the glass absorbs some energy in the same interaction.

However, not all intersections of causal processes are causal interactions. If two light rays intersect they are superimposed on one another in the locus of intersection, but after they leave that place each of them continues on as if nothing had happened. A process—such as a light beam—is causal if it can be modified or marked in a way the persists beyond the point of intersection as a result of *some* intersection with another process. Causal processes are capable of transmitting energy, information, and causal influence from one part of spacetime to another. I have argued that causal processes are precisely the kinds of causal connections Hume sought, but was unable to find. I have also argued that such connections do not violate Hume's strictures against mysterious powers.

It is important to recognize that these causal mechanisms are not necessarily deterministic. In particular, causal processes can interact probabilistically. My favorite example is Compton scattering, in which an energetic photon collides with a virtually stationary electron. The angles at which the photon and electron emerge from the interaction are not strictly determined; there is, instead, a probability distribution over a whole range of pairs of angles. By conservation of momentum and energy, however, there is a strict correlation between the two scattering angles.

The causal mechanisms of interaction and transmission are strongly local; they leave no room for what Einstein called "spooky action-at-a-distance." Interactions occur in a restricted spacetime region, and processes transmit in a spatio-temporally continuous fashion. Regrettably (to me and many others), however, quantum mechanics appears to involve violations of local causality. There seems to be a quantum mechanism, often known as "the collapse of the wave function," which is radically nonlocal, and which is not really understood as yet.

I prefer to think of the conception of explanation that emerges from these considerations as causal/mechanical. The aim of explanations of this sort is to exhibit the ways in which nature operates; it is an effort to lay bare the mechanisms that underlie the phenomena we observe and wish to explain.

§ 4. *Some New Perspectives*

During the 1960s and 1970s the ideas developed by Hempel constituted a *received view* of scientific explanation. It was based on the Hempel-Oppenheim 1948 paper, and was articulated most fully in Hempel's "Aspects of Scientific Explanation" (1965). As a result of numerous criticisms, it is fair to say, the 'received view' is no longer received. Its natural successor is the unification conception due chiefly to Friedman and Kitcher.

The causal conception as originally advocated by Scriven and others has also undergone transformation, primarily as a result of more careful and detailed analysis of causality, but also because of the admitted possibility that there are mechanisms of a noncausal type as well. It has involved an explicit recognition of the Humean critique of causality, and an attempt to overcome the Humean difficulties.

Given the history of opposition between the 'received view' and the causal view of scientific explanation, it is not surprising that philosophers continue to find opposition between the successors. Friedman, for example, contrasted *local* and *global* accounts. According to the older views of both Hempel and Scriven, explanation is a local affair, in the sense that one could give a perfectly acceptable explanation of a small and isolated phenomenon without appeal to global theories. One could give a Hempelian explanation of the electrical conductivity of a particular penny by pointing out that it is made of copper, and copper is an electrical conductor. One could give a Scrivenesque explanation of a stain on a carpet by citing the fact that a clumsy professor bumped an open ink bottle off of the desk with his elbow. In contrast to both of the foregoing accounts, Friedman's unification view requires us to look at our entire body of scientific knowledge, to see whether a given attempt at explanation reduces the number of assumptions needed to systematize that body of knowledge. Friedman's conception is patently global.

Kitcher (1989) has made a related distinction between conceptions he characterizes as "bottom-up" and "top-down." The Hempelian approach illustrates the bottom-up way. We begin by explaining the conductivity of a penny by appeal to the generalization that copper is a conductor. We can explain why copper is a conductor in terms of the fact that it is a metal. We can explain why metals are conductors in terms of the behavior of their electrons. And so it goes from the particular fact to the more general laws until we finally reach the most comprehensive available theory. The causal/mechanical approach has the same sort of bottom-up quality. From relatively superficial causal explanations of particular facts we appeal to ever more general types of mechanisms until we reach the most ubiquitous mechanisms that operate in the universe. Kitcher's top-down approach, in contrast, looks to the most general explanatory schemes we can find, and works down from there to characterize such items as laws and causal relations.

In a spirit quite different from those of Friedman and Kitcher, Peter Railton has advocated an approach that makes the bottom-up and top-down, as well as the local and global, conceptions complementary rather than contrary. In "Probability, Explanation, and Information" (1981) he introduces the concept of an *ideal explanatory text* which is extremely global and detailed. He suggests, however, that we hardly ever seek to articulate fully such an ideal text. Rather, we focus on portions or aspects of the ideal text, and try to illuminate these. When we succeed we have furnished *explanatory information.* Different investigators, or groups of investigators, have different interests and work on different portions of the ideal text. Pragmatic considerations determine for a given individual or group what portion of the ideal text to look at, and in what depth of detail.

§ 5. *Rapprochement?*

My main purpose in this paper is to consider the possibility, suggested by Railton's work, that the successors of the 'received view' and its causal opponent, are actually compatible and complementary. Let me begin by offering a couple of examples.

(1) A friend recounted the following incident. Awaiting takeoff on a jet airplane, he found himself sitting across the aisle from a young boy who was holding a helium-filled balloon by a string. In order to pique the child's curiosity, he asked the boy what he thought the balloon would do when the airplane accelerated rapidly for takeoff. After considering for a few moments, the boy said he thought it would move toward the back of the cabin. My friend said *he* believed that it would move forward in the cabin. Several other passengers overheard this claim and expressed skepticism. A flight attendant even wagered a miniature bottle of Scotch that he was wrong—a wager he was happy to accept. In due course, the pilot received clearance for takeoff, the airplane accelerated, and the balloon moved toward the front of the cabin. And my friend enjoyed a free drink courtesy of the flight attendant.

Two explanations of the balloon's strange behavior can be given. First, it can be pointed out that, when the plane accelerates, the rear wall of the cabin exerts a force on the air molecules near the back, which produces a pressure gradient from rear to front. Given that the inertia of the balloon is smaller than that of the air it displaces, the balloon tends to move in the direction of less dense air. This is a straightforward causal explanation in terms of the forces exerted on the various parts of the physical system. Second, one can appeal to Einstein's principle of equivalence, which says that an acceleration is physically equivalent to a gravitational field. The effect of the acceleration of the airplane is the same as that of a gravitational field. Since the helium balloon tends to rise in air in the earth's gravitational field, it will tend to move forward in the air of the cabin in the presence of the aircraft's acceleration. This second explanation is clearly an example of a unification-type explanation, for the principle of equivalence is both fundamental and comprehensive.

(2) A mother leaves her active baby in a carriage in a hall that has a smooth level floor. She carefully locks the brakes on the wheels so that the carriage will not move in her absence. When she returns she finds, however, that by pushing, pulling, rocking, bouncing, etc., the baby has succeeded in moving the carriage some little distance. Another mother, whose education includes some physics, suggests that next time the carriage brakes be left unengaged. Though skeptical, the first mother tries the experiment and finds that the carriage has moved little, if at all, during her absence. She asks the other mother to explain this lack of mobility when the brakes are off.

Two different explanations can be given; each assumes that the rolling friction of the carriage is negligible when the brakes are off. The first (at least in principle) possible explanation would involve an analysis of all of the forces exerted by the baby on the carriage and the carriage on the baby, showing how they cancel out. This would be a detailed causal explanation. The second explanation would appeal to the law of conservation of linear momentum, noting that the system consisting of the baby and the carriage is essentially isolated (with respect to horizontal motion) when the brake is off, but is linked with the floor, the building, and the earth when the brake is on. This is an explanation in the unification sense, for it appeals directly to a fundamental law of nature.

The first point I should like to emphasize in connection with both of these examples from physics is that both explanations are perfectly legitimate in both cases; neither is intrinsically superior to the other. Pragmatic considerations often determine which of the two types is preferable in any particular situation. Invocation of Einstein's principle of equivalence would be patently inappropriate for the boy with the balloon, and for the other adults in that situation, because it is far too sophisticated. All of them could, however, understand a clear explanation in terms of forces and pressures. The two examples are meant to show that explanations of the two different types are not antithetical, but rather, complementary.

I should like also to consider a famous example from biology, (3) the case of the peppered moth in the vicinity of Liverpool, England. This moth spends much of its life on the trunks of plane trees, which naturally have a light-colored bark. Prior to the industrial revolution the pale form of this moth was prevalent, for its light color matched the bark of the tree, and consequently provided protection against predators. During the industrial revolution in that area, air pollution darkened the color of the tree bark, and the dark (melanic) form of the peppered moth became prevalent, because the darker color then provided better protection. In the post-industrial-revolution period, since the pollution has been drastically reduced, the plane trees have again acquired their natural light-colored bark, and the light form of the peppered moth is again becoming dominant.

In this example, like the two preceding, two different explanations are available to account for the changes in color of the moth. The first has already been suggested in the presentation of the example; it involves such evolutionary considerations as natural selection, mutation, and the heritability of traits. This is the unification style of explanation in terms of basic and comprehensive principles biology. The second kind of explanation is biochemical in nature; it deals with the nitty-gritty details of the causal processes and interactions involved in the behavior of DNA and RNA molecules and the synthesis of proteins leading up to the coloration of the moth. In order to explain the above mentioned changes in color, it would have to take account also of the births, deaths, and reproductive histories of the individual moths. Although such a causal/mechanical explanation would be brutally complex, it is possible in principle. Again, there is nothing incompatible about the two kinds of explanation.

The use of this kind of biological example leads into a more general consideration regarding the status of functional explanations. In the case of the peppered moth, we were clearly concerned with a function of the coloration, namely, its function as camouflage for protection against predators. Although some philosophers have tried to cast doubt upon the legitimacy of functional explanations, I am strongly inclined to consider them scientifically admissible. In my opinion, Larry Wright, a student of Scriven, has given the most convincing theory (1976). Wright makes a distinction between *teleological explanations* and *functional ascriptions*, but his accounts of them are fundamentally similar; they involve what he calls a *consequence-etiology*. It is a *causal* account in which the cause of a feature's presence is the fact that in the past when it has been present it has had a certain result or consequence. It is not *just* that it has had such consequences in the past; in addition, the fact that it had such consequences is causally responsible for its coming into being in the present instance.

I shall use the term "functional explanation" to cover both teleological explanations and functional ascriptions in Wright's terminology. Although functional explanations in this sense are causal, they do not have a fine-grained causal character—that is to say, they do not go into the small details of the causal processes and interactions involved. They do, of course, appeal to the *mechanisms* of evolution—inheritance and natural selection—but these are coarse-grained mechanisms. Wright is, however, perfectly willing to admit that fine-grained causal explanations are also possible. Just as we can give a straightforwardly mechanistic account of the workings of a thermostat, whose function is to control temperature in a building, so also is it possible, at least in principle, to give a thoroughly physicochemical account of some item that has a biological function, such as the color of the peppered moth. Although some philosophers have maintained that the mechanistic explanation, when it can be given, supersedes the functional explanation. Wright tional explanation need not give way to the mechanistic explanation. I think he is correct in this view.

The philosophical issue of the status of functional explanations is not confined to biology; the problem arises in psychology, anthropology, and the other social or behavioral sciences as well. Whether one regards Freudian psychoanalysis as a science or not, the issue is well-illustrated in that discipline. According to Freud, the occurrence and the content of dreams can be explained functionally. The dream preserves sleep by resolving some psychological problem that might otherwise cause the subject to awaken. The content of the dream is determined by the nature of the problem. However, even if it is possible to provide a psychoanalytic explanation of a given dream, it may also be possible to give another explanation in completely neurophysiological terms. This would be a fine-grained causal explanation that incorporates the physical and chemical processes going on in the nervous system of the subject. I am suggesting that the two explanations need not conflict with one another, and I believe that, in this opinion, I am in agreement with Freud.

§ 6. *Can Quantum Mechanics Explain?*

Ever since the publication of the famous Einstein-Podolsky-Rosen paper (1935), there has been considerable controversy over the explanatory status of the quantum theory. Einstein seems to have taken a negative attitude, while Bohr appears to have adopted an affirmative one. As the discussion has developed, the question of local causality versus action-at-a-distance has become the crucial issue. The EPR paper showed that there could, in principle, be correlations between remote events that seem to defy explanation. Further work by David Bohm, John Bell, and A. Aspect have shown that such correlations actually exist in experimental situations, and that *local hidden-variable* causal explanations are precluded. A clear and engaging account of these issues can be found in N. David Mermin (1985). Because these fine-grained causal explanations are not possible, many philosophers, myself included, have concluded that quantum mechanics does not provide explanations of these correlations. As I suggested above, there seem to be mechanisms at the quantum level that are noncausal, and that are not well understood.

Other philosophers have taken a different attitude. On the basis of the undeniable claim that quantum mechanics is a highly successful theory in providing precise predictions and descriptions (they are statistical, but extremely successful), we need ask for no more. The quantum theory can be formulated on the basis of a small number of highly general principles, and it applies universally.

In terms of the distinct conceptions of scientific explanation we have been discussing, it seems that quantum theory provides explanations of the unification type, but it does not provide those of the causal/mechanical sort. This situation contrasts with that in other scientific disciplines where, as we have seen, explanations of both kinds are possible, at least in principle. The same circumstance may seem to occur in anthropological or sociological explanations of some human institutions, where we can give functional explanations of certain phenomena, but fine-grained causal explanations are far beyond our grasp. In contrast to quantum mechanics, however, there is no solid theoretical basis for claiming that fine-grained causal explanations are impossible in principle in these disciplines.

In answer to the question of this section, "Can quantum mechanics explain?" the answer must be, for the time being at least, "In a sense 'yes', but in another sense 'no'." In (W. Salmon, 1984, pp. 242–59) I had admitted only the negative answer to this question.

§ 7. *Two Concepts of Explanation*

One of the chief aims and accomplishments of science is to enhance our understanding of the world we live in. In the past, it has often been said that this aim is beyond the scope of science—that science can describe, predict, and organize, but that it cannot provide genuine understanding. Among philosophers of science and philosophical scientists at present there seems to be a fair degree of consensus about the ability of science to furnish explanations, and therefore to contribute to our understanding of the world. As is obvious from the foregoing discussion, however, there is no great consensus on the nature of this understanding. I should like to suggest that it has at least two major aspects, corresponding to the two types of explanation that have been discussed above.

On the one hand, understanding of the world involves a general world-view—a *Weltanschauung*. To understand the phenomena in the world requires that they be fitted into the general world-picture. Although it is often psychologically satisfying to achieve this sort of agreement between particular happenings and the world-view, it must be emphasized that psychological satisfaction is not the criterion of success. To have *scientific* understanding we must adopt the world-view that is best supported by all of our scientific knowledge. The fundamental theories that make up this world-view must have stood up to scientific test; they must be supported by objective evidence. Perhaps we need not ask what makes a scientific world-picture superior to a mythic or religious or poetic world-view. Nevertheless, I would ask, and try to give an answer. The superiority of understanding based on a scientific world-view lies in the fact that we have much better reason to regard that world-view as true—even though some other world-view might have more psychological appeal.

The conception of understanding in terms of fitting phenomena into a comprehensive scientific world-picture is obviously connected closely with the unification conception of scientific explanation. It also corresponds closely to the goal of many contemporary scientists who are trying to find one unified theory of the physical world—for example, those who see in so-called "superstring theory" a TOE (theory of everything). Many scientists seem to believe that it is both feasible and desirable to try to discover some completely unified theory that will explain everything.

On the other hand, there is a different fundamental notion of scientific understanding that is essentially mechanical in nature. It involves achieving a knowledge of how things work. One can look at the world, and the things in it, as black boxes whose internal workings we cannot directly observe. What we want to do is open the black box and expose its inner mechanisms.

This conception of scientific explanation brings us face to face with the problem of realism versus anti-realism. Although one can open up a clock to find out how it works by direct observation of its parts, one cannot do so with a container full of a gas. Gases are composed of molecules or atoms (monatomic molecules), and these are too small to be observed by means of the naked eye, a magnifying glass, or a simple optical microscope. The search for mechanistic explanations often takes us into the realm of unobservables. Although some philosophers, past and present, have adopted a skeptical or agnostic attitude toward unobservables, I think it is possible to argue persuasively that we can have genuine knowledge of such micro-entities as bacteria and viruses, atoms and molecules, electrons and protons, and even quarks and neutrinos. I believe we can have compelling inductive evidence concerning the existence and nature of such entities (W. Salmon, 1984, chap. 8). The ideal of this approach is to have the capacity to provide explanations of natural phenomena in terms of the most fundamental mechanisms and processes in the world.

Consideration of these two conceptions of scientific explanation suggests that there may be a kind of explanatory duality corresponding to the two approaches. To invoke Railton's terminology and Kitcher's metaphor, we can think in terms of reading the ideal explanatory text either from the bottom-up or from the top-down. There are, of course, intermediate stages between the two extremes—there are degrees of coarse- or fine-grainedness. The kinds of examples brought up by Wright in his comparison of the course-grained consequence-etiology explanations with the fine-grained mechanical explanations do not usually appeal to either the most general laws of nature or the most fundamental physical mechanisms. Moreover, we often give mechanical explanations of everyday contrivances, such as the hand-brake on a bicycle, without any appeal to unobservables.

It is extremely tempting to try to bring a linguistic distinction in English to bear on the explanatory duality I am discussing, but I fear it also holds certain risks. Sometimes we seek explanations by asking "How?" and sometimes by asking "Why?" Consider, for example, "How did the first large mammals get to New Zealand?" and "Why did the first large mammals go to New Zealand?" The answer to the first question is that they were humans, and they went in boats. I do not know the answer to the second question, but it undoubtedly involves human purposes and goals. The danger in making the distinction between how-questions and why-questions in terms of examples of this sort is that it easily leads to anthropomorphism—to the conclusion that 'genuine' explanations always involve an appeal to goals or purposes. That would certainly be a step in the wrong direction. But not all examples have this feature. If one asks *why* a penny conducts electricity, one good answer is that it is made of copper, and copper is a good conductor. If one asks *how* this penny conducts electricity, it would seem that a mechanism is called for. A story about electrons that are free to move through the metal would be an appropriate answer. In this case, the why-question elicits an appeal to a general law; the how-question evokes a description of underlying mechanisms.

§ 8. *Conclusion*

The attempt to gain scientific understanding of the world is a complicated matter. We have succeeded to some extent in reaching this goal, but what we have achieved to date has taken several centuries of effort on the part of many people, some of whom were or are towering geniuses. Many of the explanations that have been found are extraordinarily difficult to understand. When we think seriously about the very concept of scientific understanding, it does not seem plausible to expect a successful characterization of scientific explanation in terms of any simple formal schema or simple linguistic formulation. It is not surprising that there might be the kind of duality I have been discussing.

The situation may be even more extreme. As one of my graduate students, Kenneth Gemes, has suggested, perhaps it is futile to try to explicate the concept of scientific explanation in a comprehensive manner. It might be better to list various explanatory virtues that scientific theories might possess, and to evaluate scientific theories in terms of them. Some theories might get high scores on some dimensions, but low scores on others—recall our brief consideration of quantum mechanics. I have been discussing two virtues, one in terms of unification, the other in terms of exposing underlying mechanisms. Perhaps there are others that I have not considered. The foregoing discussion might serve as motivation to search for additional scientific explanatory qualities.

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RESUMEN

El propósito de Wesley Salmon es argumentar en favor de la tesis de que es posible una reconciliación, en grado significativo, entre las dos grandes tradiciones en el análisis de la explicación científica. La idea central es que en estas tradiciones se defienden enfoques que son compatibles y complementarios.

Una tradición es la que se inicia con Carl G. Hempel; las ideas desarrolladas por este autor constituyeron, en los años sesenta y setenta, la "concepción aceptada". Su sucesor natural es la concepción de la unificación, debida principalmente a Michael Friedman y a Philip Kitcher. La otra tradición es la iniciada por Michael Scriven, quien defendió una concepción causal de la explicación. Las transformaciones que ha ido sufriendo esta concepción han sido el resultado de análisis cada vez más cuidadosos y detallados de la causalidad. Uno de los principales responsables de esta transformaciones es Wesley Salmon.

En la concepción de la unificación que propone Friedman, la tesis básica es que incrementamos nuestro conocimiento científico del mundo en la medida en que podemos reducir el número de supuestos independientemente aceptables para explicar los fenómenos naturales.

Salmon desarrolla la concepción causal haciendo una elucidación de ciertos mecanismos causales: interacciones y procesos causales; defiende además la tesis de que los mecanismos causales pueden ser indeterministas. Como piensa que el objetivo de la explicación científica es mostrar las formas en que opera la naturaleza —lo cual implica descubrir los mecanismos que subyacen a los fenómenos—, considera que su enfoque es mejor entendido como una concepción causal y mecánica.

El concepto de "texto explicativo ideal" introducido por Peter Railton, junto con el análisis del nivel pragmático de la investigación científica que propone este mismo autor, son considerados por Salmon como una base muy adecuada y prometedora para mostrar que la concepción mecánico-causal y la concepción de la unificación, son reconciliables —compatibles y complementarias.

Salmon ofrece una serie de ejemplos para apoyar su tesis. Entre ellos, algunos son utilizados para hacer ver que la explicación funcional —tal como la concibe Larry Wright— no tiene por qué en-

trar en conflicto con las explicaciones mecánico-causales "de grano fino". Ambas son legítimas y complementarias.

La naturaleza de la comprensión científica, según Salmon, abarca al menos dos aspectos, los cuales corresponden a los dos tipos de explicación analizados. Por una parte, la comprensión de los fenómenos requiere que sean acomodados en una visión general del mundo. Este aspecto de la comprensión está estrechamente relacionado con la concepción de la explicación como unificación. Por otra parte, la comprensión requiere un conocimiento de cómo opera la naturaleza, de los mecanismos responsables de los fenómenos. Este aspecto es el que recupera la concepción mecánico-causal. En vista de las complejidades del concepto de comprensión científica, concluye Salmon, no parece plausible una caracterización de la explicación científica en términos de algún esquema formal o formulación lingüística simple.

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