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EXPLANATION

Theoretical Approaches and Applications

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THE WHY AND HOW OF EXPLANATION: AN ANALYTICAL EXPOSITION

> The most direct, and in a sense the most important, problem which our conscious knowledge of nature should enable us to solve is the anticipation of future events, so that we may arrange our present affairs in accordance with such anticipation.
>
> Heinrich Hertz
> *The Principles of Mechanics* [Hertz (1894) 1956], p.1.

> Once again I repeat: the aim of physics at its most fundamental level is not just to describe the world but to explain why it is the way it is.
>
> Steven Weinberg
> *Dreams of a Final Theory* [Weinberg (1992) 1994], p.219.

> At the end of this century we can seriously argue that, although metaphysics and theology may serve as sources of inspiration or consolation, intellectually illuminating explanations are to be found in the realms of natural science. It is not necessary to depart from science to have genuine understanding of the world and what transpires within it.
>
> Wesley Salmon
> *Causality and Explanation* [Salmon 1998], p.91.

1. INTRODUCTION

Heinrich Hertz and Steven Weinberg — two illustrious physicists separated by a century — exemplify by their respective views of physics one of the crucial transitions in philosophy that this century of science has undergone. We are concerned here with the role assigned to theories, their constituting laws and consequently the criteria by which they are supposed to be compared and evaluated. Should a theory enable us to be solely "in advance of the facts," as Hertz had stipulated [Hertz (1894) 1956], p.1, or should it aim at what seems to be a rather loftier objective: increasing our understanding of "why... [the world] is the way it is," as Weinberg demanded [Weinberg (1992) 1994], p.219? The tension is then between on the one hand successful prediction based on appropriate representation of

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phenomena and on the other hand explanatory power grounded in schemes of explanation.

The apparent transition from mere prediction to explanation is reflected in the growing philosophical interest in the notion of scientific explanation. As the century drew to its close, optimism seems to prevail: "intellectually illuminating explanations are to be found in the realms of natural science," writes confidently Wesley Salmon [Salmon 1998], p.91, one of the principal contributors to this field of study and indeed to this volume. This allegedly successful transition and its critique have motivated the present volume.

I open the analytical section with a couple of instructive historical case studies of the tension between prediction and explanation. I continue with a general exposition of the essential relation between knowledge and explanation and discuss a few pivotal problems in the philosophy of explanation. I then proceed to present the formal model of explanation and in view of its limitations I introduce various suggestions that have been proposed by several authors to overcome the difficulties. In particular, three principal positions have been consolidated: the epistemic, the ontic and the pragmatic position. This is the juncture where I embark on an analytical exposition of each of the papers that comprise the book. The book has two parts: (1) theoretical approaches, and (2) applications. The second part is further divided into (i) critical expositions of the use of explanation, and (ii) studies of limits of explanation.

The tension between prediction and explanation comes vividly to the fore in the case of Robert A. Millikan's definitive experimental demonstration of the photoelectric effect: under certain conditions, when light impinges on a metal surface electrons are emitted and may close an electric circuit. The effect is commonly deployed in optical control devices such as sliding doors of elevators and various alarm systems. Millikan convincingly showed in 1916 that the photoelectric effect is governed by the theory which Einstein had proposed earlier in 1905.

During the year 1905 Einstein published in the *Annalen der Physik* five papers which revolutionized twentieth century physics. Einstein himself referred however to only one paper explicitly as revolutionary; he entitled that paper: "On a Heuristic Point of View Concerning the Production and Transformation of Light" [Stachel 1998], pp.177-198. He wrote in a letter to a close friend: "The paper deals with radiation and the energetic properties of light and is very revolutionary" (quoted by [Stachel 1998], p.5). In this paper, Einstein called for a Newtonian view of light; that is, light as consisting of a localized energy. He then suggested that these packets of radiant energy could "kick" electrons from the metal surface. Accordingly, Einstein envisaged that,

> in the propagation of a light ray emitted from a point source, the energy is not distributed continuously over ever-increasing volumes of space, but consists of a finite number of energy quanta localized at points of space that move without dividing, and can be absorbed or generated only as complete units [ibid.], p.178.

This was indeed a "very revolutionary" hypothesis. It suggested that matter and radiation can interact only through the exchange of quanta of energy [ibid.], p.21. The idea ran against the dominant contemporaneous Maxwellian view that light is an electromagnetic wave.

Einstein did not receive the Nobel prize for his relativity theories. It was rather the experimental confirmation of the photoelectric equation which Einstein had developed on the basis of the idea of the light "energy quanta", that eventually convinced the Nobel committee that he was worthy of the prize. In his presentation speech of Einstein's Nobel Prize, Arrhenius made it clear that the Nobel Committee for Physics had chosen Einstein especially for his contributions to the quantum theory: his studies of specific heat and the photoelectric effect [*Nobel Lectures* 1967], p.479. Arrhenius declared that,

> Einstein's law of the photo-electrical effect has been extremely rigorously tested by the American Millikan and his pupils and passed the test brilliantly. Owing to these studies by Einstein the quantum theory has been perfected to a high degree [ibid.], p.480.[1]

A year later, in 1923, it was the turn of Millikan to be awarded the Nobel Prize. The Nobel Committee stated that Millikan received the prize "for his work on the elementary charge of electricity and on the photoelectric effect" [*Nobel Lectures* 1965], p.49. The chairman of the Nobel Committee was of the opinion that if Millikan's experimental studies of the photoelectric effect had given a different result, the law of Einstein would have been without value. The chairman stressed that the award of the previous year to Einstein was due to the fact that Millikan had confirmed the law experimentally [ibid.], p.53. The results of Millikan's painstaking experimental work on the photoelectric effect did indeed establish the validity of Einstein's equation and moreover provided an accurate determination of *h*, the Planck constant. On his part, Millikan referred to the complexity and intricacy of his experimental arrangement as “a machine shop in vacuo” [Millikan 1916], p.361.

There is however a pungent sting to this seemingly classical story in the annals of science of a happy conjecture followed by a successful experimental confirmation. Millikan, who demonstrated brilliantly the validity of the equation for the photoelectric effect, rejected outright and categorically Einstein’s hypothesis of the light-quanta which in point of fact underwrites the theory. The equation was fine, but the hypothesis was “reckless”. Millikan opined in his concluding paper that Einstein had put forward “the bold, not to say the reckless, hypothesis of an electromagnetic light corpuscle of energy $h\upsilon$“ [ibid.], p.355. Millikan considered this hypothesis “reckless” since,

> an electromagnetic disturbance which remains localized in space seems a violation of the very conception of an electromagnetic disturbance, and second because it flies in the face of the thoroughly established facts of interference [ibid.].

Millikan found himself in a curious conundrum: although his meticulous experiments confirmed Einstein’s equation of the photoelectric effect, he felt strongly that the semi-corpuscular theory by which Einstein had arrived at his equation was at that time wholly untenable [ibid.], p.383. Despite the “complete success of the Einstein equation, the physical theory of which it was designed to be the symbolic expression is found,” according to Millikan, “so untenable that Einstein himself,” Millikan believed, “no longer holds to it” [ibid.], p.384. Pais traced this view of Millikan to a remark Einstein himself had made in 1911, at the first Solvay Congress. “I insist,” Einstein then said, “on the provisional character of... [the] concept [of light-quanta] which does not seem reconcilable with the experimentally verified consequences of the wave theory” (quoted by [Pais 1983], p.383). Millikan conceded, however, that

> the photoelectric effect..., however it is interpreted, if only it is correctly described by Einstein’s equation, furnishes a proof which is quite independent of the facts of black-body radiation of the correctness of the fundamental assumption of the quantum theory... It materializes, so to speak, the quantity “*h*” discovered by Planck through the study of black-body radiation and gives us a confidence inspired by no other type of phenomenon that the primary physical conception underlying Planck’s work corresponds to reality [Millikan 1916], p.385.

Driven by his disbelief in the notion of the light quanta, Millikan went on to develop a substitute for Einstein’s theory based largely on Planck’s theory [ibid.], pp.385-88 (see also [Millikan 1922], pp.231-38).[2] By putting a different interpretation on Einstein’s experimentally confirmed equation, Millikan found himself in a peculiar situation:

> We are in the position of having built a very perfect structure and then knocked out entirely the underpinning without causing the building to fall. It stands complete and apparently well tested, but without any visible means of support. These supports must obviously exist, and the most fascinating problem of modern physics is to find them. Experiment has outrun theory, or, better, guided by erroneous theory, it has discovered relationships which seem to be of the greatest interest and importance, but the reasons for them are as yet not at all understood [Millikan 1922], p.230.

Here we have the crystallization of the problem: the equation of the photoelectric effect “stands complete and apparently well tested, but without any means of support.” With the Einstein equation for the photoelectric effect Millikan could be, to borrow the phrase from Hertz, “in advance of the facts,” but he could not, to recall Weinberg’s demand, “explain why... [the effect] is the way it is.” The concept of the light-quanta is at the root of the successful prediction of the theory, but Millikan remained at a loss as to its explanatory power, since at that time the light-quanta, as a physical entity, simply did not make any sense.[3]

Millikan’s perplexity reflects the issue at stake. Predictions worked successfully, yet (at least for Millikan) no explanation had been forthcoming. To use Millikan’s wording, there were no “supports” for the successful predictions. The crucial point to note is that for Millikan, as for most scientists, philosophers and the general Western public, it is natural to think that “these *supports* must obviously exist,” and that science ought to find them. But why, why should such supports exist?

The belief that such supports exist has a long and respected history in the Western tradition. In fact, Millikan’s perplexing situation is similar to the one in which Newton found himself. Having claimed to successfully explain the phenomena of the heavens and of the sea by the power of gravity, Newton openly admitted that he had not yet assigned the cause of this power. In a well known passage in the *Principia*, the General Scholium, Newton stated explicitly that,

> hitherto I have not been able to discover the cause of those properties of gravity from phenomena, and I frame no hypotheses; for whatever is not deduced from

> the phenomena is to be called an hypothesis; and hypotheses, whether metaphysical or physical, whether of occult qualities or mechanical, have no place in experimental philosophy [Newton (1687) 1995], pp.442-43.

Did Newton really explain the phenomena of the heavens and the sea? He himself was apparently not happy with this unclear situation and he spent much of the time of his later career seeking unsuccessfully an explanation of gravitational motion in terms of causal agency [McMullin 1984], p.208.

The Western tradition of pursuit of knowledge cannot bear the bare phenomenon. The philosopher, the scientist as well as the man on the Clapham omnibus are all seekers of explanations. As the prominent philosopher of science Carl G. Hempel saw it,

> To explain the phenomena in the world of our experience, to answer the question "why?" rather than only the question "what?" is one of the foremost objectives of empirical science [Hempel 1965], p.245.

It is in fact the desire for systematic explanations based on factual evidence that generates science [Nagel (1961) 1979], p.4. Indeed, in this tradition one is prepared to entertain beliefs *solely* on the basis of explanations — to be sure, the best available explanations. One is set, that is, to hold a belief "on the basis of an evaluation of hypotheses with respect to how well they explain the evidence" [van Fraassen 1989], p.142.

But why? "Why ask, 'Why?'?" [Salmon 1998], pp.125-41. Why should one seek explanations when there are many methods of inquiry that can provide foresights, be they prognostications, general expectations or accurate predictions? Why should one seek explanations, particularly in science, when predictions based on scientific theories would suffice? After all, a prediction is less epistemologically demanding than an explanation; while the former is a proposition which need not be an argument or its consequence, the latter is an argument [Scheffler 1957]. This very question, this very inquiry completes however a circle and takes the critical observer back to the departure point — the quest for explanations: one seeks to explain the preference that one commonly has for explanation over prediction. It appears that within this tradition there is no escape from that frame of mind: an "insistent craving for reasons why" [van Fraassen 1989], p.352, or to paraphrase Sartre, "we are condemned to explanation". The tension then between prediction and explanation persists, but as we shall see shortly one model of explanation has sought to weld the two together.

Scientific explanation stands in an especial relation to knowledge. Strictly speaking, the relation is parasitic. Explanation draws on knowledge to effect its epistemological import: the placing of the singular, particular bare phenomenon — the *explanandum*, that is, the phenomenon to be explained — into a pattern which is imposed on phenomena from without — the *explanans*. There is however a growing interest in the reverse direction, namely, the dependence of knowledge on explanation. Inference to the Best Explanation, which constitutes one of the main themes of the theoretical section of the present book, is designed to provide a ground for belief on the basis of explanation, and the best explanation at that.

Explanation is obtained when the singular, isolated, particular phenomenon[4] — the explanandum, is shown to partake in a general scheme — the explanans. The phenomenon to be explained is presented in explanation as a particular case of a general pattern, a scheme. Clearly, it is crucial for the understanding of explanation to determine the nature of the general pattern, that is, what kind of order governs the scheme? Is it, for example, a law or a mere empirical regularity?

The notion of miracle may help throw light on explanation by examining explanation from an extreme perspective. A miracle is by definition a unique phenomenon that cannot partake in any uniformity; it cannot be subject to any order. "A miracle," says Hume, "is a violation of the laws of nature" [Hume (1748) 1993], p.148. As such it cannot be an object for explanation. Any attempt to explain it, that is, to embed the miraculous phenomenon in a general pattern, to associate it with a certain scheme, in sum to subject it to a certain order, would result in annulling the miraculous nature of the phenomenon (cf., [Houston 1994]).

Clearly, the general pattern, scheme or order must be in one way or another directly relevant to the phenomenon, otherwise a convincing and satisfying embedding would not be obtained. To say that the phenomenon belongs to the "over-powering unity of the All" [Mach 1974], p.288 is to say too much: it is too general and hence inconsequential. To obtain a satisfying explanation one needs to establish a strongly related link between the elements of the explanation and the object of explanation. As von Wright remarked, indicating a law which states the universal concomitance of, say, two general characteristics would simply not suffice for a satisfying explanation [von Wright 1971], p.19. The scheme therefore must represent a framework of interest — "the view from somewhere," to use Redhead's apt formulation [Redhead 1990], p.153.

Consider by way of comparison the Omniscient Being. By definition it takes no specific interest in that or the other localized aspect of the infinite knowledge that it possesses. It simply has no preferences; its knowledge is neither context nor interest dependent. Like all the propositions of logic [Wittgenstein (1921) 1978], #6.127, all knowledge for the Omniscient Being is of equal status. This is why the Omniscient Being would not be able to explain. In fact, as van Fraassen pointed out, that Being would lack the notion of explanation altogether [van Fraassen (1980) 1990], p.130. Explanations are at once expressions of the weakness and the greatness of the human mind: weakness — that the mind needs to explain due to its possession of only finite knowledge; greatness — that the mind has the capacity to conceive of the general and thereby infer as well as conjecture explanations.

In view of this outline, the essential difficulty with explanation may be discerned right away. It is two-fold: first there is the imposition of a pattern, a scheme or an order on phenomena from without, and then the imposed pattern should be relative to subjective interests. In the final analysis, explanation is subjective: context as well as interest dependent, which leads in turn to the problem of psychological contentment. "Why seek a teleological explanation?" asks Brandon, expressing dissatisfaction with some explanation. He proceeds to illustrate:

> In adult *Homo sapiens* there are marked morphological differences between the sexes. Why is this? Answer: Different sex specific hormones work during ontogenetic development to produce these differences. Is this answer satisfying? That depends on the question one's really asking. One might be asking what's behind these hormonal differences, what's it all for. Whether or not this question is interesting or answerable, it is not answered by the above bit on hormones. One might want more [Brandon 1998], p.79.

Clearly, the subjective discontentment: "one might want more," is psychologically motivated. It is the truncation problem: the when-does-one-stop question. When is one content with the answer one receives for the Why question? It would certainly be disturbing were scientific explanation not free from considerations of psychological satisfaction and mental comfort [Salmon 1998], pp.9, 76. Hempel, the doyen of scientific explanation, is aware of the difficulty and he promptly drew the relevant boundaries:

> it is important to distinguish here understanding in the psychological sense of a feeling of empathic familiarity from understanding in the theoretical, or cognitive, sense of exhibiting the phenomenon to be explained as a special case of some general regularity [Hempel 1965], pp.256-57, see also p.258.

The philosopher of explanation is seeking to assuage the desire for explanation by providing an epistemological basis for explanation. Clearly, a psychological basis would not do in philosophy. However, the price to be paid for replacing psychology with epistemology is high. Be it theoretical or cognitive, the general regularity of which the explanandum is a special case, is imposed from without and is claimed to exist, underlying — or "supporting", to recall Millikan's wording — the phenomenon to be explained. The positivists refused to pay this high price. Their objection to explanation originated in the prohibition to have recourse to metaphysics and especially so when metaphysical elements are being introduced from without. Hertz's *Principles of Mechanics* is an instructive example of this objection.

In the Introduction to his *Mechanics*, Hertz attempted to lay bare the processes of the mind, both the intuitive and the discursive, and to provide criteria of evaluation for physical theories, criteria that are not dependent on explanatory features. Hertz offered what Boltzmann had earlier called "mathematical phenomenology":

> Physics must... pursue the sole aim of writing down for each series of phenomena, without any hypothesis, model or mechanical explanation, equations from which the course of the phenomena can be quantitatively determined.

Hertz's reformulation of Maxwell's theory is the *locus classicus* of this approach. By starting from bare differential equations describing experimental results rather than from detailed physical pictures, Hertz offered physicists a fine example of mathematical phenomenology: "To the question, 'What is Maxwell's theory?' I know of no shorter or more definite answer," Hertz stated, "than the following: Maxwell's theory is Maxwell's system of equations."

This approach was very appealing to Mach, who was one of the leading positivists at the turn of the century. Mach admired this way of doing physics. In his view, Hertz followed the "ideal of a physics free of mythology." Indeed, for Hertz,

> Scientific accuracy requires of us that we should in no wise confuse the simple and homely figure, as it is presented to us by nature, with the gay garment which we use to clothe it. Of our own free will we can make no change whatever in the

> form of the one, but the cut and color of the other we can choose as we please (quoted by [Hon 1997], p.64, see also pp.63-64).

The positivists sought to free science of its mythology: experimentally inaccessible metaphysical schemes that are supposed to underwrite, to support, phenomena. In their view science should only describe physical events rather than explain them; explanation had to go. This prohibition of asking "Why?" and the focus instead on the "How?" has to be placed in its historical setting. As Carnap intimated,

> When I was young and part of the Vienna Circle, some of my early publications were written as a reaction to the philosophical climate of German idealism. As a consequence, these publications and those by others in the Vienna Circle were filled with prohibitory statements [Carnap 1966], p.12.

The objection was against an understanding that could be obtained only by finding metaphysical causes that were behind phenomena and not accessible to the scientific method. As we have seen at the outset of this study, that philosophical atmosphere has changed. In Carnap's view,

> we are no longer worried by why-questions. We do not have to say, "Don' t ask why", because now, when someone asks why, we assume that he means it in a scientific, nonmetaphysical sense. He is simply asking us to explain something by placing it in a framework of empirical laws [Carnap 1966], p.12.

The philosopher who consolidated that change is Carl G. Hempel. Together with Paul Oppenheim, Hempel constructed a formal scheme of explanation, the Deductive-Nomological (D-N) model, that was designed to avoid the metaphysical threat. They published in 1948 a seminal study in which they set to shed light on the function and essential characteristics of scientific explanation

> by means of an elementary survey of the basic pattern of scientific explanation and a subsequent more rigorous analysis of the concept of law and the logical structure of explanatory arguments [Hempel 1965], p.245.

Hempel acknowledged the pioneering works of a few philosophers, amongst them J. S. Mill, K. Popper and H. Feigl, and modestly claimed that his study only stated explicitly some fundamental points which had been already recognized [ibid.], footnote 7, p.251 (cf., [Salmon 1998], pp.81, 302ff.). However, the apparent aim was far more ambitious than a mere rehearsal of a few recognized fundamental points. As Glymour acutely observed, Hempel and Oppenheim were intent on providing "an account of the logical structure of 'explains' in much the way that the logical tradition of Frege, Russell, Whitehead, and Hilbert had provided accounts of the logical structure of 'is a proof of'" [Glymour 1984], p.178 (cf., [Salmon 1998], p.313).

According to Hempel and Oppenheim, the logical structure of explanation demands that the question "*Why* does the phenomenon occur?" should be construed as meaning: "according to what general laws, and by virtue of what antecedent conditions does the phenomenon occur?" [Hempel 1965], p.246. They argued that in view of the logical structure of deductive explanation, the explanation of a phenomenon consists in the subsumption of the phenomenon under laws or generally under a theory [ibid.], p.264.

Inherent to this analysis are logical and empirical conditions of adequacy, which a sound scientific explanation must satisfy. Hempel and Oppenheim stipulated three logical conditions of adequacy: (1) the explanandum must be logically deducible from the information contained in the explanans; (2) the explanans must contain general laws, and (3) the explanans must have empirical content. To these three logical conditions they added a crucial fourth one which is an empirical condition of adequacy: (4) the sentences constituting the explanans must be true [ibid.], pp.247-48. This latter condition is of course foreign to logical analysis, hence the notion of "potential explanation" which satisfies only the three logical conditions, while "actual explanation" meets the requirements of all the four criteria [ibid.], footnote 3, p.249 (see also p.273).

The four necessary conditions of adequacy make this formal, logical analysis applicable to both scientific explanation and prediction. Explanation and prediction have been thus welded into the same logical scheme, so much so that Hempel and Oppenheim treated them as interchangeable notions distinguished only by a pragmatic, time dependent feature [ibid.], p.249 (see however [Scheffler 1957]). By fusing explanation and prediction into a deductive system with a clear logical structure, Hempel and Oppenheim believed to have eliminated the psychological aspect of explanation. As Glymour pointed out, they had not intended their scheme to be

> an analysis of when it is appropriate to say that someone has explained something to someone; instead, they had specified the logical structure that fully explicit, nonstatistical explanations in the natural sciences would typically have if there

> were any, and which actual explanations in the natural sciences typically abbreviate [Glymour 1984], p.178.

It is perhaps not surprising that this logical structure that fuses explanation and prediction is in fact the very logical structure of the Newtonian method. The three logical conditions of adequacy reflect from a different perspective the very method of Newtonian physics.

The success of physics in explaining the inanimate world may be traced back to its roots in positional astronomy. As Schrödinger remarked, there is a direct genealogical link from quantum mechanics of its both central formulations: the matrix- and the wave-form, via analytical mechanics of its central theorems due to Hamilton and Jacobi, over to Newton's general laws of motion and gravitation, and further back to Kepler's celestial physics [Schrödinger 1984], pp.562-64. The idea of a God given, pervasive law that links the initial conditions, i.e., the state of the system, with its nature, e.g., its motion, has made mechanics the prototype of exact physical science to be emulated by all the sciences. This is not surprising since it is a most ingenious solution for connecting the necessary and general element of the law with the contingent and particular aspect of the system. Put differently, Newton's profound and useful idea of dividing the analysis into a dynamical and a static part allows for a coherent and apparently successful connection between the law of the evolution of the system and its state at some point in time. This kind of analysis finds its immediate expression in the infinitesimal calculus where the solution of the differential equations (the dynamical part) requires constants of integration (the static part) which are nothing else but the initial conditions of the system — its state. Notwithstanding the great (many would say revolutionary) innovations and discoveries which have taken place since the time of Newton, nothing substantial has changed in the comprehensive application of this successful Newtonian methodology [Hon 2000], pp.295-96.

It may be perceived immediately that the two distinct features of the explanans in Hempel and Oppenheim's scheme, namely, statements of antecedent conditions and general laws, relate directly to the initial conditions of the system at stake and the dynamical laws that govern its evolution in time, respectively. Clearly, the predicted — calculated mathematically and hence deductively obtained — future state that the system will possess, which is nothing else but the explanandum, may be now deductively inferred and thus explained by having recourse to Hempel and Oppenheim's logical analysis. It can therefore be safely claimed that the deductive logical structure of explanation captures effectively the Newtonian method of physical inquiry, the very method that has shaped the sciences in the modern era.

Had Hempel and Oppenheim succeeded in their objective, there would have been available purely logical criteria for evaluating theories. On the basis of a logical structure alone, it would be fully determinate, as Glymour observed, "what singular sentences a given theory could potentially explain, and what sentences it could not possibly explain" [Glymour 1984], p.178. In other words, as Salmon put it, "any phenomenon in our universe, even in domains in which we do not yet have any scientific knowledge, must be either amenable to explanation by... [the logical account of Hempel and Oppenheim] or else not susceptible to any sort of scientific explanation" [Salmon 1998], p.313. Had the logical structure of explanation been successful, there would have been available a universal logical account of explanation by which one could decide what to accept and believe.

The project failed however to achieve these goals. It has transpired that the logical structure which Hempel and Oppenheim constructed is not sufficiently selective and may result in nonsensical explanations, or alternatively provide explanation of improbable events. In other words, the three logical conditions of adequacy and the crucial additional empirical criterion have been shown to be neither sufficient nor necessary for an adequate explanation. The flagpole example is a case in point: using the D-N model one can explain the height of the flagpole by the length of the shadow it casts (see [Salmon 1990] for a plethora of critiques of the model; cf., [Salmon 1998], pp.309-13). The force of Hempel and Oppenheim's project, as Glymour succinctly put it, "was not the execution but the vision" [Glymour 1984], p.178. There is no doubt that the vision of a purely logical structure of explanation has remained seductive [Lipton 1992], p.691.

In view of the difficulties which the logical structure of scientific explanation has encountered, other possibilities, some with long traditions, have been taken up and pursued. These philosophical theories of explanation aim at making the logical structure of scientific explanation more selective and pragmatic. One possibility is to add an objective structure which imposes physical conditions over and above the logical ones. This is the position that Salmon takes. He embeds the explanandum in a causal structure [Salmon 1984]. Thus scientific explanation provides "knowledge of the mechanisms of *production* and *propagation* of structure in the world" [Salmon 1998], p.139, emphasis in the original (cf., p.71). Explanation, according to Salmon, should exhibit the ways in which nature operates.

Salmon's view of scientific explanation links well with the view of Kitcher [Kitcher 1989; Kitcher 1993] that regards unification as the key of scientific explanation. Scientific explanations provide a unified world picture in which disparate phenomena appear to fit together into a coherent scheme of unifying principles of nature. As Salmon observes, the two approaches complement each other: one may show the explanandum to partake in a unifying overall scheme and one may equally expose the underlying causal mechanism that brought about the explanandum [Salmon 1998], p.90.

Another possibility is to return to the subjective aspect of explanation and to acknowledge it explicitly as an inherent feature. Hence, psychological conditions of belief, interest and, generally, elements that are context dependent become essential to explanation. This is the position which van Fraassen takes. For van Fraassen an explanation constitutes a triadic relation: the explanans and the explanandum are always found within a defined context. This approach constitutes part of his general anti-realist conception of science which he calls "constructive empiricism" [van Fraassen 1989], pp.192-93; [van Fraassen 1990], ch. 5 (cf., [Glymour 1984], pp.178, 188; [Salmon 1998], pp.313-15).

We have then three distinct positions vis-à-vis theories of explanation. While the logical, subsumption scheme of explanation is epistemological, explanations that are based on causal structures and unifying schemes are ontological[5] and those that are explicitly interest- and context-dependent may be regarded as pragmatic.

2. THEORETICAL APPROACHES

Against this background of the philosophy of explanation, the book opens with a section entitled "Theoretical Approaches". This section comprises a constructive philosophical dialogue between Peter Lipton and Wesley C. Salmon as well as a study by Orna Harari-Eshel of Aristotle's theory of knowledge and its bearing on explanation. The dialogue between Lipton and Salmon leads the discussion of explanation further afield: the emphasis of the exchange being on the transition from explanation to knowledge and not the other way around. In other words, at issue is the relation between explanation and confirmation. To use Lipton's expressions, the dialogue focuses mainly on the "instrumental good of explanation": that feature of

explanation which may guide the acquisition of knowledge, as distinct from the "intrinsic good of explanation" — the feature that provides an understanding of the explanandum.

Peter Lipton opens the debate with a general analysis of the notion of explanation with a view to finding the best vehicle for explanation. He begins his essay, **"What Good is an Explanation?"** with a search for the intrinsic good of explanation and proceeds then to discuss its instrumental good as it is found in Inference to the Best Explanation. Lipton seeks in a sense an explanation of explanation. To avoid the dormative trap of valuing explanations because of their explanatory power, he presents five different accounts of what explanation amounts to which he then tests by three categories.

According to Lipton, explanations might (1) provide reasons for belief, (2) make familiar, (3) unify, (4) show to be necessary, or (5) give causes. The first two notions: reason and familiarity, are epistemological conceptions of explanation; the last two, namely, necessity and causation, render explanations ontological, while the middle conception — unification — may turn either way depending on the kind of analysis which one applies.

The three general features of explanation with which Lipton tests these five conceptions of explanation are: (1) "Knowing that" vs "understanding why"; (2) Truncation of the "why regress" by the proposed explanation, and (3) The self-evidencing explanation: when the explained phenomenon gives ground for belief that the explanation is correct.

Applying these criteria to the five conceptions of explanation, Lipton reaches the conclusion that only causation passes the three tests and with flying colors at that. To be sure, causation is not without difficulties; still it has remained, according to Lipton, the best model of explanation. He proceeds to query: Why causes explain? In effect, Lipton is taking one step up the "why regress". In Lipton's view, the crucial feature in explaining why causes rather than effects explain, is that causes make the difference between the phenomenon occurring and its not occurring. Causes put us, as it were, in control of the phenomenon.

While the discussion of causes illustrates the intrinsic good of explanation, Lipton's further presentation of the Inference to the Best Explanation exhibits the instrumental good of explanation. This inference shows how explanatory practices are tools for the acquisition of true beliefs. The idea is that explanatory considerations constitute a guide to inference both in science and in ordinary life: inference is being made from

However, a word of caution is in place. We have seen at the outset of this essay how predictions may have the upper hand, as it were, over explanations. The success of Einstein's photoelectric equation and Newton's gravitational equation in predicting the pertaining phenomena does not rest on explanatory hypotheses. When an explanatory hypothesis is put forward it has to compete hard with the predictive power of the very theory it is supposed to explain. In the final analysis it is prediction that counts; prediction bears the objective signature while explanation remains relative to human interest. The act of explaining, Hacking opines,

> is largely a feature of the historical or psychological circumstances of a moment. There are times when we feel a great gain in understanding by the organization of new explanatory hypotheses. But that feeling is not a ground for supposing that the hypothesis is true [Hacking 1983], p.53.

In the last century, especially in its latter part, explanation became a major issue of concern. Many philosophers of science have tried hard to shake off the subjective aspect of explanation and to consolidate a formal foundation. They have sought to render explanation either epistemological or ontological. However, consider once again the formal character of the D-N model. As we have seen, it reflects the Newtonian methodology and so it appears that the logicist approach to explanation has advanced the subject further in details and rigor but not in substance. Thus in conclusion it is worth noting with Kuhn that from a historical perspective a great divide may be discerned [Kuhn 1977], pp.26-30. On the one hand there is the impressive development of substantive scientific theories and on the other hand — the fairly stagnant and cohesive nature of the formal models of explanation.

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NOTES

[1] On the deliberation of the Nobel Committee see [Pais 1983], pp.502-512.

[2] For an overview of the various interpretations of this effect see [Humphreys 1968], pp.43-59; cf., [Stuewer 1970].

[3] The skepticism concerning Einstein's light quantum hypothesis prevailed till about 1924. It was the discovery of the Compton effect that provided, together with the photo-electric effect, that "interlocking theoretical and experimental matrix" [Stuewer 1970], p.263, from which a concept such as the light quanta derives its validity.

[4] There is no need to distinguish here between a particular fact and some general regularlity as different objects of explanation.

[5] The unifying scheme of explanation may also be regarded as epistemological. Thus unification mediates between the epistemic and the ontic conception of explanation.

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