Scientific Explanation: Three Basic Conceptions[1]

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When one takes a long look at the concept (or concepts) of scientific explanation, it is possible and plausible to distinguish three fundamental philosophical views. These might be called the *epistemic*, *modal*, and *ontic*. They can be discerned in Aristotle's *Posterior Analytics* and they are conspicuous in the twentieth-century literature. In its classic form--the *inferential version*--the epistemic conception takes scientific explanations to be arguments. During the period of almost four decades since the publication of the landmark Hempel-Oppenheim article, "Studies in the Logic of Explanation" (1948), the chairman of this symposium (Carl G. Hempel) has done more than anyone else to articulate, elaborate, and defend this basic conception and the familiar models that give it substance (Hempel 1965), though it has, of course, had many other champions as well. According to the modal conception, scientific explanations do their jobs by showing that what did happen had to happen. Among the recent proponents of this conception, Rom Harré and Edward Madden (1975), D. H. Mellor (1976), and G. H. von Wright (1971) come readily to mind. The ontic conception sees explanations as exhibitions of the ways in which what is to be explained fits into natural patterns or regularities. This view, which has been advocated by Michael Scriven (1975) and Larry Wright (1976), usually takes the patterns and regularities to be causal. It is this third conception--the ontic conception--that I support.

If these conceptions are viewed in the context of classical physics, construed in a Laplacian deterministic fashion, there seems not much point in distinguishing them or trying to choose among them--the distinctions give a strong appearance of being merely verbal. In the more contemporary context of possibly indeterministic physics, these distinctions seem to me to take on a great deal of significance. Thus, a careful examination of probabilistic or statistical explanation turns out to be crucial. In that context, the choice among the basic conceptions has major philosophical ramifications. The purpose of this paper is to examine each conception in its strongest form, and to consider the basic philosophical issues involved in accepting or rejecting each.[2]

PSA 1984, Volume 2, pp. 293-305

1. The Epistemic Conception

Since the objections to the inferential version of the epistemic conception are quite familiar, I shall not spend much time rehearsing them. Let me simply cite one issue that has crucial importance for the present discussion, namely, the problem of explaining events that are relatively improbable. According to Hempel's most detailed account, an explanation is an argument to the effect that the event to be explained was to be expected, given the explanatory facts. D-N (deductive-nomological) explanations obviously have this character, for the explanandum follows with deductive certainty from the explanans. An I-S (inductive-statistical) explanation shares this characteristic, for the explanandum is rendered highly probable with respect to the explanans. The main problem for the present discussion is the status of events that occur with middling or low probabilities. The point is well-illustrated by a familiar, though admittedly highly oversimplified, example. If two heterozygous brown-eyed parents produce a brown-eyed child, that fact can presumably be explained statistically on the basis of the 0.75 probability of such an occurrence.[3] If these same parents produce a blue-eyed child, that fact seems unexplainable because of its low probability. Nevertheless, as Richard Jeffrey (1969) and others have argued persuasively, we understand each of these occurrences equally well. To say that we can explain the one, but not the other, is strangely asymmetrical.

In a more recent discussion of statistical explanation, Hempel (1977) relinquished his high probability requirement, thus apparently removing the difficulty associated with the explanation of improbable occurrences. He did not, however, pursue the ramifications of this change for his whole theory of scientific explanation. I suspect that it creates more problems than it solves--for example, violating the very covering law conception that he had ably defended in all of his preceding treatments of scientific explanation.

During the past fifteen years, two other versions of the epistemic conception have been advanced. The first is an <u>information-theoretic version</u> first proposed by James Greeno (1970) and later defended by Joseph Hanna (1978). This approach is extremely useful, but if it is supplemented, as Kenneth Sayre (1977) has suggested, with suitable consideration of the mechanisms of transmission of information, it should be reclassified under the ontic conception, which stresses physical mechanisms.

The second is an <u>erotetic version</u> first broached by Sylvain Bromberger (1966) and recently elaborated by Bas van Fraassen (1980). Bromberger's account was restricted to explanations of the D-N sort, whereas van Fraassen's theory deals explicitly with statistical explanations. Space does not permit a detailed exposition and critique of van Fraassen's theory (see Salmon 1984); nevertheless, I should like to make two comments. First, it is a subtle and well-worked-out theory--to my mind the most promising of any falling under the epistemic conception. Second, it presents a basic philosophical issue on which we take opposite sides.

The problem centers upon van Fraassen's handling of the contrast class. On his view, each properly formulated explanation-seeking why-question presupposes a set of alternatives, one and only one of which (the topic) is true. To revert to the eye-color example, we might choose a contrast class consisting of the alternatives {the child has brown eyes, the child has blue eyes}. Now, I have no objection whatever to the invocation of the contrast class; indeed, I require just such a class under the name "explanandum-partition". But van Fraassen requires the explanans to "favor" the topic--to enhance the probablility of the topic vis-à-vis the other alternatives. That seems to cause no problem in case we want to explain the eye color of the brown-eyed child, but it causes exactly the same kind of difficulty as Hempel's high-probability requirement in the case of the blue-eyed child. The requirement of favoring has the consequence that we can explain the more probable outcome when it occurs, but not the less probable outcome when it occurs. Since, as noted before, it seems that we understand each alternative equally well, or equally poorly, the favoring requirement leads to an unsatisfactory asymmetry. I shall return to this issue below.

2. The Modal Conception

The most obvious major consequence of indeterminism is that it appears to make the modal conception untenable. This conception seems to be impaled on the horns of a trilemma: one must either (1) make an a priori commitment to determinism; or (2) admit degrees of necessity; or (3) grant that, to the extent that there are irreducibly statistical occurrences, they are inexplicable. Since, to my mind, a priori commitments to determinism are archaic and degrees of necessity unilluminating, we seem to be stuck with the third alternative. The problem is that quantum mechanics, which is arguably the most powerful explanatory theory in all of science, appears to require a statistical interpretation. Even if, in the end, it should turn out that a deterministic interpretation is tenable, we must not at present beg that question by a priori fiat.

The adherents of the modal conception have one further line of defense. It is natural--as von Wright has seen--to emphasize the strong affinity between their conception and Hempel's D-N model and to reject Hempel's I-S model. There is, however, one additional model--the D-S (deductive-statistical)--to which they might appeal. This model, it will be recalled, is used to explain a statistical regularity by showing that it follows with necessity from one or more statistical laws (and initial conditions in some cases). There is, however, no real need to treat the D-S model as a separate model, for D-S explanations (being both deductive and nomological) automatically qualify as D-N explanations, as long as we do not insist (as Hempel has not) that D-N explanations embody only universal laws. The advocate of the modal conception can accept, as legitimate D-N explanations, those of the deductive-statistical variety as well. Following this tack, the modal theorist can claim that quantum mechanics does explain statistical regularities--for example, tunneling phenomena--while denying that it explains any individual occurrences at all.

Confronted with the example of eye color, the modal theorist might say that Mendelian genetics does explain the fact that among all heterozygous brown-eyed parents, three-fourths of the children have brown eyes and one-fourth have blue-eyes, though it offers no explanation at all of the eye color of any given child. The difficulty is that it also precludes explanation of distributions in large samples, for example, why among a sample of a thousand children of such parents about 750 were brown eyed.

Many proponents of the modal conception will be totally unsatisfied by the eye-color example, for it is easy to suppose that underlying Mendelian statistical distributions there are deterministic causal mechanisms, and consequently, there is the possibility in principle of providing D-N explanations in all such cases. So let us take another example that involves different physical systems but the same probability distribution. Suppose that a single tritium atom is placed in a container, that the container is sealed for twenty-four and a half years, and that it is reopened at the end of that period. Since the half-life of tritium is twelve and a quarter years, there is a probability of three-fourths that it will have undergone spontaneous radioactive decay, transmuting it into a helium-3 atom, and a probability of one-fourth that it will still be intact. According to this view, we can explain the fact that three-fourths of all tritium atoms decay in any period of twenty-four and a half years, but we cannot explain the decay of any single tritium atom, the nondecay of any single tritium atom, or the percentage of decays in any restricted collection of tritium atoms in any given span of time.

There might be some plausibility in arguing that theoretical science does not contain explanations of individual events or restricted sets of events--only explanations of universal or statistical regularities--but I do not think it is true. Rutherford wanted to explain why small numbers of alpha particles were deflected through large angles by gold foil. Hiraizumi wondered why small numbers of matings of fruit flies produced radically non-Mendelian distributions of eye colors. But even if we grant the point about theoretical science, one can hardly doubt that applied science often tries to explain individual occurrences or limited sets of occurrences. And this is true in cases--such as the onset of a given disease in a given patient--in which D-N explanations are not available. A philosophical account of scientific explanation that excludes the explanations provided by applied science can hardly be considered adequate.

3. The Ontic Conception

There is a fundamental intuition--shared, I believe, by almost everyone who thinks seriously about the matter--according to which causality is intimately involved in explanation. Those who are familiar with Hume's critique of causality may deny the validity of that intuition by constructing noncausal theories of scientific explanation. Others may skirt the issue by claiming that the concept of causality is clear enough already, and that further analysis is unnecessary. My own view is (1) that the intuition is valid--scientific explanation does involve causality in an extremely fundamental fashion--and (2) that causal concepts do stand in serious need of further analysis.

It may be possible--though I seriously doubt it--to construct a regularity analysis of causality that would be adequate within the context of Laplacian determinism. The most promising such approach is J. L. Mackie's treatment of the problem in terms of INUS conditions

(Mackie 1974). In the contemporary scientific context, in which irreducibly statistical laws may well obtain, it seems necessary to admit that causal relations may also be irreducibly statistical. Among the authors who have tried seriously to construct theories of probabilistic causality, several--for example, I. J. Good (1961-1962), Hans Reichenbach (1956), and Patrick Suppes (1970)--have tried to found their analyses on statistical regularities. Although I do not have any knock-down argument to support my contention, my sense of the objections to such theories convinces me (at least tentatively) that no such regularity analysis of probabilistic causality will be adequate. We must, instead, look to the causal mechanisms.

Two causal mechanisms seem to me to be fundamental. First, there are spatiotemporally continuous causal processes that transmit causal influence from one part of spacetime to another. Causal processes must be distinguished from pseudo-processes. Pseudo-processes exhibit considerable regularity, thus closely resembling causal processes. However, pseudo-processes do not possess the ability to transmit causal influence. Causal processes are distinguished from pseudo-processes by the fact that causal processes can transmit marks, while pseudo-processes cannot.

The second causal mechanism is the causal interaction. When two or more causal processes intersect in spacetime, they may or may not produce lasting modifications in one another. If they do, the intersection constitutes a causal interaction. Pseudo-processes do not enter into causal interations. Pseudo-processes are produced by causal processes, and these causal processes that give rise to pseudo-processes can participate in causal interactions. Thus, a pseudo-process may be momentarily altered by intersection with another process (causal or pseudo), but such modifications do not persist beyond the locus of the intersection.

When these causal mechanisms are deployed, it is possible to distinguish two distinct aspects of causal explanation. First, in many cases the explanation of an event tells the causal story leading up to its occurrence. To explain the presence of a worked bone that radiocarbon dates to 30,000 years ago in an Alaskan archaeological site requires a causal account of how it got there. Since no well-authenticated New World sites of human habitation are nearly that old, one possible explanation accounts for the age of the bone by hypothesizing that the mammoth died 30,000 years ago, and its carcass was preserved in ice for many millenia before it was found and worked by a human artisan (Dumond 1980). Explanations of this sort can be called (following Larry Wright's felicitous terminology) <u>etiological</u>.

Other explanations account for a given phenomenon by providing a causal analysis of the phenomenon itself. For example, we explain the pressure exerted by a gas on the walls of a container in terms of momentum exchanges between the molecules and the walls. Such explanations may be termed <u>constitutive</u>.

In many cases, I presume, causal explanations possess both etiological and constitutive aspects. To explain the destruction of Hiroshima by a nuclear bomb, we need to explain the nature of a chain reaction (constitutive aspect) and how the bomb was transported by airplane, dropped, and detonated (etiological aspect).

According to the ontic conception--as I see it, at least--an explanation of an event involves exhibiting that event as it is embedded in its causal network and/or displaying its internal causal structure. The causal network, external or internal, consists of causal processes transmitting causal influence and causal interactions in which the structures of the interacting processes are modified. The whole structure is probabilistic. When two processes--such as an alpha particle and the nucleus of a gold atom--intersect there is a certain probability distribution for scattering of the alpha particle at various angles. When a single process--such as an amoeba--is simply transpiring there is a certain probability that it will split into two processes--in the case of the amoeba, undergoing mitosis that yields two daughter amoebas. In the case of the tritium atom, a neutron decays into a proton and an electron, thus transmuting hydrogen-3 into helium-3.

The ontic conception, in the causal version I have tried to elaborate, faces two major problems. First, there is the question of whether adequate analyses of the basic causal concepts have been furnished. I hope that the answer is 'yes', but in case it is not, further work would need to be done toward that goal.

The second--and far more difficult problem--concerns quantum mechanical explanation. Remote correlational phenomena of the type first treated in the famous Einstein-Podolsky-Rosen paper (1935), and widely discussed at present in connection with Bell's inequality, suggest that there are fundamental difficulties in principle in attempting to provide causal explanations in terms of spatiotemporally continuous causal processes and localized interactions in the quantum domain. I am not inclined to dispute this claim. Rather, I should say, it appears that causal explanations of the sort discussed above are adequate and appropriate in many domains of science, but that other mechanisms--possibly of a radically noncausal sort--operate in the quantum domain. If that is true, then we need to learn what we can about those mechanisms, so that we can arrive at a satisfactory characterization of quantum mechanical explanation. It may turn out that the causal conception of scientific explanation has limited applicability; nevertheless, the ontic conception could be maintained in a mechanistic version even as applied to quantum phenomena.

To the best of my knowledge all of the problematic cases involve quantum mechanical systems each of which is in a pure state that can be described by a single wave function. In each such case the problem arises out of an interaction of that system with a measuring apparatus that results in the "reduction of the wave packet" or "collapse of the wave function". What kind of mechanism is this? I do not pretend to know, but I suspect that no one else does either. In his address to the 1982 PSA meeting on the present situation in the philosophy of quantum mechanics, Howard Stein (1983) maintained that our lack of understanding is so profound that we do not even know whether there is in nature any such process as reduction of the wave packet. Under these circumstances, it is hardly surprising that we have no satisfactory treatment of quantum mechanical explanation.

Proponents of the epistemic conception might claim to have a viable account of quantum mechanical explanation, for there is a well-established scientific theory that correctly predicts the outcomes of the remote correlation experiments and other puzzling quantum phenomena. This is, perhaps, another instance of the principle that one person's counterexample is another person's modus ponens. To my mind, the fact that what quantum theory offers qualifies under the epistemic conception--at least in the inferential version--as correct scientific explanation constitutes strong evidence of the inadequacy of the epistemic conception of scientific explanation.

It is a basic principle of my approach that we cannot get very far in attempting to understand scientific explanation if we try to articulate a universally applicable "logic of scientific explanation". What constitutes an adequate explanation depends crucially, I think, on the kind of world in which we live; moreover, what constitutes an adequate explanation may differ from one domain to another in the actual world. Even if a causal account of explanation cannot be extended into the quantum domain, that does not mean that its application in other domains is illegitimate. The ontic conception mandates attention to the mechanisms that actually operate in the domain in which explanation is sought.

4. A Criterion of Adequacy

One preeminent criterion of adequacy (which I shall call "CA-I") has guided much of the discussion of scientific explanation for a long time; I do not know when or by whom it was first explicitly formulated; W. Stegmüller (1973) calls it "the Leibniz principle". Careful consideration of this criterion will, I think, bring out some of the basic philosophical issues separating the three general conceptions of scientific explanation outlined above. According to CA-I,

> If, on one occasion, the fact that circumstances of type C obtained is taken as a correct explanation of the fact that an event of type E occurred, then on another occasion, the fact that circumstances of type C obtained cannot correctly explain the fact that an event of type E' (incompatible with E) occurred.

Most philosophers, I believe, have taken this criterion as an unexceptionable condition of adequacy for any theory of scientific explanation, and surely within the Laplacian deterministic context it <u>is</u> a correct criterion. It is satisfied by D-N explanations, and within the deterministic context, every event is explainable by a D-N explanation. As long as the high-probability requirement is maintained, I-S explanations also satisfy this criterion, for, under any given conditions, it is impossible for both the occurrence and the nonoccurrence of a given type of event to have probabilities greater than one-half. If, however, the high-probability requirement is relinquished, it is not clear how the foregoing criterion can be satisfied.

In the case of eye color, for example, genetically identical pairs of parents produce brown-eyed children three-fourths of the time and blue-eyed children one-fourth of the time. Unless we can produce further information that would enable us to provide D-N explanations of the eye color of offspring, the adherent of the modal conception will claim that we have no explanation of either outcome. The advocate of the epistemic conception who allows for the traditional I-S model will admit the explanation of the more probable outcome but not that of the less probable. If I am correct in thinking that we understand the less probable outcome just as much or as little as we understand the more probable one, then the asymmetry in this epistemic approach becomes unacceptable. One is driven to saying that we understand both or we understand neither. Because of the reasons already offered for rejecting the modal approach, I claim that we can have explanations of both. This violates the fundamental criterion CA-I above. I'm sure that many philosophers will maintain that, with this admission, I have just dug my own grave.

Let us examine for a moment the rationale for holding the foregoing criterion sacrosanct. Its main point, I think, is to rule out certain familiar sorts of pseudo-explanation. We do not want to allow the dormitive virtue to explain the power of opium to produce sleep. We do not want to allow an appeal to the will of God to explain whatever happens. We do not want to allow a psychoanalytic theory that is compatible with all possible behavior to have explanatory power. CA-I is not, however, required to do that job. The dormitive virtue theory is patently too ad hoc to have legitimate scientific status. The will of God "explanation" is scientifically unacceptable because it appeals to a supernatural agency. Psychoanalytic theories that are compatible with all possible psychological phenomena cannot be scientifically well confirmed. To rule out such cases as these we do not need CA-I. It suffices to require that scientific explanations appeal to bona fide scientific laws and theories.

If indeterminism is true--and I think we must allow for that possibility in our theories of scientific explanation--then circumstances of a type C sometimes yield an outcome E and sometimes one or more other outcomes E' that are incompatible with E. Heterozygous brown-eyed parents sometimes have brown-eyed offspring and sometimes blue-eyed. When the offspring is brown-eyed the explanation is that the parents are both brown-eyed and heterozygous, and three-fourths of all children of such parents are brown-eyed. When the offspring is blue-eyed the explanation is that the parents are brown-eyed and heterozygous, and one-fourth of all children of such parents are blue-eyed. A tritium atom left alone in a box for twenty-four and half years sometimes yields a tritium atom in the box and sometimes a helium-3 atom in the box. When a helium-3 atom is found, the explanation is that the tritium atom placed in the box underwent beta-decay and was transmuted to helium-3, and three-fourths of all tritium atoms undergo such decay in that period of time. When a tritium atom is found, the explanation is that the tritium atom placed in the box remained intact, and that happens to one-fourth of such atoms in that period of time.

Strong protest is likely to be raised at this point on the ground that none of the foregoing explanations is acceptable, for we cannot explain why the eye-color is brown rather than blue or blue rather than brown. Nor can we explain why the tritium atom decayed rather than remaining intact or remained intact rather than decaying. The point can be put in terms of van Fraassen's contrast class. In the eye-color example, the contrast class contains blue and brown. In the case of the brown-eyed child, I should say, we can explain why the topic is true, and we know that the only alternative is false, but we cannot explain why the one rather than the other obtains.

The demand that a satisfactory explanation of any occurrence must contain the "rather than" component stems most naturally from the modal conception of scientific explanation. According to this conception, an explanation explains by showing that what did happen had to happen, from which it follows that no incompatible alternative could have happened. Such an explanation would explain why the alternative did not happen because under the circumstances it could not have happened. To my mind, this demand for the "rather than" component stems from the Laplacian deterministic context in which the same circumstances always lead to the same outcome. If one holds on to the modal conception, the natural response to indeterminism is to suppose that it makes explanations of certain kinds of occurrences impossible. The Laplacian orientation strikes me as scientifically anachronistic.

If one supports the epistemic conception, there is a strong temptation to identify explanation and rational expectability. In the deterministic context rational expectability takes the form of deductive certainty. In the indeterministic context, the type of expectability can be weakened, allowing for high inductive probability. This weakening can still allow for the "rather than" condition, for if one outcome is highly probable, the alternatives must all be rather improbable. It makes sense to expect the probable outcome rather than an improbable alternative even though we are sometimes wrong in such expectations. An "explanation" of a low-probability occurrence is likely to be rejected as any sort of genuine explanation. How, for example, can one be said to have explained the presence of a tritium atom in the container if it is reasonable to bet three-to-one against that outcome under the stated conditions?

In van Fraassen's erotetic version of the epistemic conception the "rather than" condition is preserved through the requirement that an adequate explanation favor the topic of the why-question.[4] This requirement is not tantamount to the high-probability requirement of the inferential version; indeed, it is even weaker than a positive relevance requirement. Nevertheless, in the simple case of a contrast class with just two members, if the explanation favors the more probable alternative vis-à-vis the less probable one it cannot also favor the less probable alternative vis-à-vis the more probable one. The erotetic version, like the inferential version, focuses upon rational expectability. The form of the expectability requirement in the erotetic version is more subtle, but it still leads to what seems to me to be an unappealing asymmetry. This is the price paid to avoid violating CA-I.

To shift from the epistemic to the ontic conception involves a radical gestalt-switch. It involves relinquishing rational expectability as a hallmark of successful scientific explanation. Instead of asking whether we have found reasons to have expected the event-to-be-explained had the explanatory information been available in advance, we focus on the question of physical mechanisms. Scientific understanding, according to this conception, involves laying bare the mechanisms--etiological or constitutive, causal or noncausal--that bring about the fact-to-be-explained. If there is a stochastic process that produces one outcome with high probability and another with low probability, then we have an explanation of either outcome when we cite the stochastic process and the fact that it gives rise to the outcome at hand in a certain percentage of cases. The same circumstances--the fact that this particular stochastic process was operating--explains the one outcome on one occasion and an alternative on another occasion.

The gestalt-switch demanded by the ontic conception is perhaps most vividly seen in connection with criterion CA-I. In an indeterministic world this criterion is inappropriate; in such a world the same circumstances do explain one outcome on one occasion and an incompatible alternative on another occasion. If we do not know for sure whether our world is deterministic or indeterministic, and if we want to leave open the possibility of indeterminism, then we should not tie our basic intuitions about scientific explanation to a criterion of adequacy that is appropriate only to a deterministic world.

The Laplacian influence is pervasive and insidious; it gives rise, I suspect, to some of the most widely held intuitions regarding scientific explanation. To adopt the ontic conception involves the rejection of at least four significant doctrines:

1) An explanation of an occurrence must show that the fact-to-be-explained _was to be expected_.

2) An explanation must confer upon the fact-to-be-explained a _favored position_ vis-à-vis various alternative eventualities.

3) An explanation must show why one outcome _rather than_ another alternative occurred.

4) It is impossible that circumstances of type C can, on one occasion, explain the occurrence of an event of type E, and, on another occasion, explain the occurrence of an incompatible alternative E'. (CA-I)

It may not be easy to abandon the foregoing intuitions, but I am inclined to think they must be overcome if we are to come adequately to terms with scientific explanation in the contemporary scientific context.

Notes

[1]The material in this paper is based upon work supported by the National Science Foundation under Grant No. GS-42056 and Grant No. SOC-7809146. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of the National Science Foundation.

[2]The issues raised in this paper are discussed in much greater detail in Salmon (1984).

[3]If any reader considers a probability of 0.75 insufficient to qualify as a high probability, it is a routine exercise to construct similar

examples that involve probabilities as large as one wishes--that is, arbitrarily close to 1.

[4]It should be noted that the "rather than" condition need not be embodied in every erotetic theory. Peter Achinstein's illocutionary theory is erotetic (1983), but it does not contain any "rather than" condition.

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Causation as Explanation

Michael Scriven

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