ing the fourth decade. In addition, it has served as a major stimulus to Philip Kitcher in developing the novel unification approach to explanation embodied in "Explanatory Unification and the Causal Structure of the World" in this volume (Kitcher & Salmon 1989) especially (Bromberger 1963).

2.3 Famous Counterexamples to the Deductive-Nomological Model

At the conclusion of §1.1 we raised a number of general issues arising out of the Hempel-Oppenheim treatment of scientific explanation of particular occurrences. During the second decade many of them were vividly posed in terms of counterexamples that have since become quite standard. The existence of such a standard set is, in itself, a tribute to the solidity of the received view. Let us take a look at some of the best known.

One rather obvious problem has to do with the temporal relations between the explanatory facts (as expressed by the singular sentences in the explanans) and the fact-to-be-explained (as expressed by the explanandum-sentence). In the schema reproduced above (p. 13; H-O 1948, 249) the Cs are labeled as "antecedent conditions," but in the formal explication no temporal constraints are given. Indeed, no such temporal constraints are mentioned even in the informal conditions of adequacy. This issue has been posed in terms of the explanation of an eclipse.

(CE-1) The eclipse. Going along with the D-N model, we might, for example, regard a total lunar eclipse as satisfactorily explained by deducing its occurrence from the relative positions of the earth, sun, and moon at some prior time in conjunction with the laws of celestial mechanics that govern their motions. It is equally possible, however, to deduce the occurrence of the eclipse from the relative positions of the earth, sun, and moon at some time after the eclipse in conjunction with the very same laws. Yet, hardly anyone would admit that the latter deduction qualifies as an explanation.[10] One might suppose that the failure to impose temporal restrictions was merely an oversight that could be corrected later, but Hempel (1965a, 353) raises this question explicitly and declines to add any temporal constraint.[11]

Another issue, closely related to the matter of temporal priority, has to do with the role of causality in scientific explanation. Our commonsense notion of explanation seems to take it for granted that to explain some particular event is to identify its cause and, possibly, point out the causal connection. Hempel and Oppenheim seem to share this intuition, for they remark, "The type of explanation which has been considered here so far is often referred to as causal explanation" (H-O 1948, 250). In "Aspects of Scientific Explanation," while admitting that some D-N explanations are causal, Hempel explicitly denies that all are (1965a, 352–54).

The problems that arise in this connection can readily be seen by considering several additional well-known examples.

(CE-2). Bromberger's flagpole example. A vertical flagpole of a certain height stands on a flat level piece ground.[12] The sun is at a certain elevation and is shining brightly. The flagpole casts a shadow of a certain length. Given the foregoing facts about the height of the flagpole and the position of the sun, along with the law of rectilinear propagation of light, we can deduce the length of the shadow. This deduction may be accepted as a legitimate D-N explanation of the length of the shadow. Similarly, given the foregoing facts about the position of the sun and the length of the shadow, we can invoke the same law to deduce the height of the flagpole. Nevertheless, few people would be willing to concede that the height of the flagpole is explained by the length of its shadow.[13] The reason for this asymmetry seems to lie in the fact that a flagpole of a certain height causes a shadow of a given length, and thereby explains the length of the shadow, whereas the shadow does not cause the flagpole, and consequently cannot explain its height.

(CE-3) The barometer. If a sharp drop in the reading on a properly functioning barometer occurs, we can infer that there will be a storm—for the sake of argument, let us assume that there is a law that whenever the barometric pressure drops sharply a storm will occur. Nevertheless, we do not want to say that the barometric reading explains the storm, since both the drop in barometric reading and the occurrence of the storm are caused by atmospheric conditions in that region. When two different occurrences are effects of a common cause, we do not allow that either one of the effects explains the other. However, the explanation of the storm on the basis of the barometric reading fits the D-N model.

(CE-4) The moon and the tides. Long before the time of Newton, mariners were fully aware of the correlation between the position and phase of the moon and the rising and falling of the tides. They had no knowledge of the causal connection between the moon and the tides, so they had no explanation for the rising and falling of the tides, and they made no claim to any scientific explanation. To whatever extent they thought they had an explanation, it was probably that God in his goodness put the moon in the sky as a sign for the benefit of mariners. Nevertheless, given the strict law correlating the position and phase of the moon with the ebb and flow of the tides,[14] it was obviously within their power to construct D-N explanations of the behavior of the tides. It was not until Newton furnished the causal connection, however, that the tides could actually be explained.

One of the most controversial theses propounded by Hempel and Oppenheim is *the symmetry of explanation and prediction*. According to this view, the very same logical schema fits scientific explanation and scientific prediction; the sole difference between them is pragmatic. If the event described by E has already occurred, we may ask why. A D-N explanation consisting of a derivation of E from

laws and antecedent conditions provides a suitable response. If, however, we are in possession of the same laws and antecedent conditions before the occurrence of E, then that same argument provides a prediction of E. Any D-N explanation is an argument that, were we in possession of it early enough, would enable us to anticipate, on a sound scientific basis, the occurrence of E. Since every D-N explanation involves laws, a hallmark of explanations of this type is that they provide *nomic expectability.* [15]

In discussing the symmetry of explanation and prediction in the preceding paragraph, I was tacitly assuming that the so-called antecedent conditions in the explanans are, in fact, earlier than the explanandum event. However, in view of Hempel's rejection of any requirement of temporal priority, the symmetry thesis must be construed a bit more broadly. Suppose, for example, that the explanandum-event E occurs before the conditions C in the explanans. Then, as I construe the symmetry thesis, we would be committed to the view that the D-N explanation is an argument that could be used subsequent to the occurrence of the explanatory conditions C to retrodict E. It is quite possible, of course, that E has occurred, but that we are ignorant of that fact. With knowledge of the appropriate laws, our subsequent knowledge of conditions C would enable us to learn that E did, in fact, obtain. Parallel remarks could be made about the case in which C and E are simultaneous. Thus, in its full generality, the symmetry thesis should be interpreted in such a way that "prediction" is construed as "inference from the known to the unknown."[16]

As Hempel later pointed out in "Aspects of Scientific Explanation," the symmetry thesis can be separated into two parts: (i) Every D-N explanation is a prediction—in the sense explained in the preceding paragraph—and (ii) every (nonstatistical) scientific prediction is a D-N explanation. It is worthwhile, I think, to distinguish a *narrower symmetry thesis*, which applies only to D-N explanations of particular facts, and a *broader symmetry thesis*, which applies to both D-N and I-S explanations of particular facts. According to the narrower thesis, every *nonstatistical* prediction is a D-N explanation; according to the broader thesis, every prediction is an explanation of either the D-N or I-S variety. Given the fact that statistical explanation is not explicated in the Hempel-Oppenheim article, only the narrower symmetry thesis is asserted there. The broader thesis, as we shall see, was advocated (with certain limitations) in "Aspects."

Nevertheless, various critics of the Hempel-Oppenheim article failed to take sufficient notice of the explicit assertion that not all legitimate scientific explanations are D-N—that some are statistical. Scriven (1959) strongly attacked subthesis (i)—that all explanations could serve as predictions under suitable pragmatic circumstances—by citing evolutionary biology and asserting that it furnishes explanations (of what has evolved) but not predictions (of what will evolve). If, as I believe, evolutionary biology is a statistical theory, then Scriven's argument applies at best to the broader, not the narrower symmetry thesis. Although this argu-

ment was published in 1959,[17] it does, I believe, pose a serious problem for the theory of statistical explanation Hempel published three years later. In the same article Scriven set forth a widely cited counterexample:

(CE-5) Syphilis and paresis. Paresis is one form of tertiary syphilis, and it can occur only in individuals who go through the primary, secondary, and latent stages of the disease without treatment with penicillin. If a subject falls victim to paresis, the explanation is that it was due to latent untreated syphilis. However, only a relatively small percentage—about 25%—of victims of latent untreated syphilis develop paresis. Hence, if a person has latent untreated syphilis, the correct prediction is that he or she will not develop paresis. This counterexample, like the argument from evolutionary biology, applies only to the broader symmetry thesis.

When the narrower symmetry thesis is spelled out carefully, it seems impossible to provide a counterexample for subthesis (i)—that every explanation is a prediction (given the right pragmatic situation). That subthesis amounts only to the assertion that the conclusion of a D-N argument follows from its premises. Against subthesis (i) of the broader symmetry thesis the syphilis/paresis counterexample is, I think, quite telling.

When we turn to subthesis (ii) of the narrower symmetry thesis—i.e., that every (nonstatistical) prediction is an explanation—the situation is quite different. Here (CE-3) and (CE-4) provide important counterexamples. From the barometric reading, the storm can be predicted, but the barometric reading does not explain the storm. From the position and phase of the moon, pre-Newtonians could predict the behavior of the tides, but they had no explanation of them. Various kinds of correlations exist that provide excellent bases for prediction, but because no suitable causal relations exist (or are known), these correlations do not furnish explanations.

There is another basis for doubting that every scientific prediction can serve, in appropriate pragmatic circumstances, as an explanation. Hempel and Oppenheim insist strongly upon the covering law character of explanations. However, it seems plausible to suppose that some respectable scientific predictions can be made without benefit of laws—i.e., some predictions are inferences from particular instances to particular instances. Suppose, for instance, that I have tried quite a number of figs from a particular tree, and have found each of them tasteless. A friend picks a fig from this tree and is about to eat it. I warn the friend, "Don't eat it; it will be tasteless." This is, to be sure, low-level science, but I do not consider it an unscientific prediction. Moreover, I do not think any genuine laws are involved in the prediction. In (1965, 376) Hempel considers the acceptability of subthesis (ii) of the symmetry thesis an open question.

There is another fundamental difficulty with Hempel and Oppenheim's expli-

cation of D-N explanation; this one has to do with explanatory relevance. It can be illustrated by a few well-known counterexamples.

(CE-6) The hexed salt. A sample of table salt has been placed in water and it has dissolved. Why? Because a person wearing a funny hat mumbled some nonsense syllables and waved a wand over it—i.e., cast a dissolving spell upon it. The explanation offered for the fact that it dissolved is that it was hexed, and all hexed samples of table salt dissolve when placed in water. In this example it is *not* being supposed that any actual magic occurs. All hexed table salt is water-soluble because all table salt is water-soluble. This example fulfills the requirements for D-N explanation, but it manifestly fails to be a bona fide explanation.[18]

(CE-7) Birth-control pills. John Jones (a male) has not become pregnant during the past year because he has faithfully consumed his wife's birth-control pills, and any male who regularly takes oral contraceptives will avoid becoming pregnant. Like (CE-6), this example conforms to the requirements for D-N explanation.

The problem of relevance illustrated by (CE-6) and (CE-7) is actually more acute in the realm of statistical explanation than it is in connection with D-N explanation. Insofar as D-N explanation is concerned, it is possible to block examples of the sort just considered by any of several technical devices.[19] We will return to this issue when we discuss statistical explanation.

2.4 Statistical Explanation

In an article entitled "The Stochastic Revolution and the Nature of Scientific Explanation," Nicholas Rescher (1962) made an eloquent plea for an extension of the concept of scientific explanation beyond the limits of deductive explanation. The "stochastic revolution" yields "forcible considerations . . . that militate towards a view of explanation prepared to recognize as an 'explanation' of some fact an argument which provides a rationalization of this fact from premises which render it *not necessary but merely probable*" (ibid., 200). He adds, "To refuse to accord to such explanatory reasonings the title of 'explanation' is to set up so narrow a concept of explanation that many of the reasonings ordinarily so-called in modern scientific discussions are put outside the pale of *explanations proper* by what is in the final analysis, a fiat of definition buttressed solely by fond memories of what explanation used to be in nineteenth-century physics" (ibid. 204).

The most important development to occur in the second decade (1958–67) of our chronicle—the explicit treatment of statistical explanation—had its public inception in 1962. Although Rescher clearly recognized the inductive character of such explanations, neither he nor any of several other authors who recognized the legitimacy of statistical explanation offered an explicit model. They thought,