On Deductive-Nomological Explanation

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Abstract: Carl Hempel's D-N model of scientific explanation has fallen on hard times. Four main problems with the model are cases of tacking, irrelevance, asymmetry and probability. By introducing a minor alteration into the model, much of the groundwork laid out by Hempel can be conserved. This paper serves to introduce the D-N model, elucidate the four classes of problems mentioned, introduce the minor modifications necessary for the modified Deductive-Nomological (mD-N) model, and review the success of mD-N in dealing with these four classes of problem cases.

Key words: scientific explanation, scientific understanding, deductive-nomological model, mD-N model, necessary and sufficient conditions

Résumé : La modèle D-N d'explication scientifique de Carl Hempel se retrouve en difficultés par le temps qui court. Quatres classes d'exemples problèmatiques se présentent: tacking, irrelevance, asymmetry and probability. Par une modification assez mineure, la majorité des efforts de Hempel peuvent être conservés. Cet article a comme but d'introduire la modèle D-N de façon bref, d'élucider les quatres classes de problèmes nommées, d'introduire la modèle D-N modifiée (la modèle mD-N), et de revoir les quatres classes de problèmes en vue de la mD-N.

Mots-clefs: explication scientifique, compréhension scientifique, la modèle déductive-nomologique, modèle mD-N, conditions necéssaires et suffisantes

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According to Carl Hempel, the goal of science is not merely to describe, but furthermore also to explain phenomena, "to answer the question 'why?' rather than only the question 'what?'".[i] In this essay, I will explore Carl Hempel's deductive-nomological (D-N) model of scientific explanation,[ii] discuss some criticisms that have been brought against it, propose a minor alteration to the D-N model, and discuss its success in overcoming the objections as well as the philosophical impact on explanation that results from the modification.

Hempel's D-N model

According to Hempel, explanations are arguments: "Why did such and such a phenomenon occur?" "Because thus and so." Hempel refers to the conclusion of the explanatory argument, that is to say, to the observed phenomenon to be explained, as the explanandum. The premises of the argument, that is to say the antecedent conditions and general laws from which the conclusion follows, are together called the explanans. Hempel laid out four explicit criteria that every explanation must meet:

1. The explanandum must follow logically from the explanans.
2. The explanans must contain one or more general laws.
3. The explanans must contain empirical content, also called antecedent conditions.
4. The sentences of the explanans must be true.

Essentially, any explanation must be a sound argument; it must be deductively valid and have true premises. The explanatory power comes from the subsumption of the particular case described in the antecedent conditions under the universal (i.e.: the general law) contained in the explanans.

Because of the reliance on the logical structure of the argument, the D-N model is not only explanatory, but rather it also yields predictive power. Looking at past cases, we can use the D-N model to ask why the explanandum occurred, whereas looking to the future, we can use the D-N model to ask what, based on the antecedent conditions and general laws, *will* occur. In the retrodictive explanatory case, “the question ‘*Why* does the phenomenon occur?’ is construed as meaning ‘according to what general laws, and by virtue of what antecedent conditions does the phenomenon occur?’”[iii] In the predictive case, it is in virtue of the general laws and antecedent conditions stated that we can answer the question “What will occur?”

Allow us to go through an example. The two terminals of a battery are connected to a penny. The penny is made of copper, and the battery has a given non-zero voltage. These are all antecedent conditions. Copper is a conductive material (i.e.: if a voltage is connected across it, current will flow through it), which is our general law. Here is the explanatory argument presented formally:

The terminals of the battery are connected to the penny,

The battery has a non-zero voltage.

The penny is made of copper.

Copper is a conductive substance

Therefore, electric current runs through the penny.

The first four statements constitute the explanans, in which we find both empirical content and general laws, all of which are true in this case. The final statement, which is the explanandum event to be explained, follows logically from the explanans, and therefore all four criteria are met. The logical validity of the argument lends it both explanatory and predictive power. This power arises from the subsumption of the antecedent conditions under the general law.

Criticisms

Four criticisms brought against Hempel’s D-N model are the following: 1, tacking cases; 2, irrelevance cases; 3, asymmetry cases; 4, probability cases. Tacking cases are cases in which additional laws are “tacked onto” the law used for subsumption in our explanations. This criticism is imbedded in the nature of logical derivability: because explanatory power springs from the subsumption of a particular under a universal, and because a particular can be subsumed under a given universal as well as under that same universal with an additional, non-contradicting universal tacked on, Hempel’s model allows additional tacked laws to play a role in explanations. That is to say, if A can be subsumed under the general law B, then it can also be subsumed under the conjunction of generals laws B & C. C is a general law irrelevant to the case in question, but plays some explanatory role because we can use the conjunction B & C as our general law under which to subsume A.

Going back to our example, suppose we were to replace "Copper is a conductive substance," with "Copper is a conductive substance, and so is gold." Let us assess Hempel's four criteria for explanation. The explanandum still follows logically from the explanans. The explanans contains a general law, as well as empirical content. Lastly, the sentences of the explanans are all true. Therefore, according to Hempel's model, this argument is explanatory. The explanation of the current flowing through the penny comes from subsuming the antecedent conditions under a general law about the conductivity of copper and of gold. But gold has nothing to do with the situation, and therefore we would intuitively want to reject the notion that general laws about it lend any explanatory force to this argument.

Irrelevance cases are ones in which the explanandum follows logically from the explananans, as it ought for a good explanation. However, we recognize that the sentences of explanans, though true, are not the explanation for the explanandum. They are not explanatory because we recognize that they are irrelevant: we know that they do not answer the question of why the explanandum came about. Irrelevance cases arise because the D-N model accepts any arguments as explanatory so long as they meet Hempel's four criteria, so long as they are sound arguments, which is not a very strict criterion. Let us take the following example:

Milo hexed the salt in the shaker.

Salt from the shaker was poured into a glass of water.

All hexed salt dissolves in water.

Therefore, the hexed salt dissolves in the glass of water.

The explanans contains empirical content and general laws. These statements are true. For those who dispute the truth of the general law, remember that hexed salt is a subset of salt *tout court*, and so if we say that hexed salt does not dissolve in water, it follows that it must be false that salt dissolves in water. Lastly, the explanandum follows logically from the explanans. The less superstitious among us certainly do not want Milo's hexing to play any explanatory role in the dissolution of the salt, but this argument follows all the criteria for the D-N model.

Asymmetry cases are ones in which we have a general law that is actually a proportion or ratio. Because we can solve for any one term in the ratio given the other terms, we can give arguments that follow the D-N model but are intuitively not explanatory, as they do not answer the question of why the phenomenon occurs. For example, pendula operate according to Galileo's pendulum law,[iv] which states that the period of a given pendulum increases proportionately to the square of the pendulum's length. Now, we can give a D-N explanation for the length of the pendulum given this formula and the duration of its period:

The duration of the period (T) of a given pendulum is 2π seconds.

The period and length of a pendulum stand in the relation $T = 2\pi (L/g)^{1/2}$.

Therefore, the length of the pendulum (L) is 9.8 metres.

It is intuitively jarring to say that the duration of a pendulum's period can explain the length of its string, but this is what the D-N model commits us to. The converse, however, explaining the duration of a period by the length of a pendulum, does not seem unintuitive, which suggests that perhaps our intuition is jarred by using a dependent variable (i.e.: one we cannot change directly) to explain an independent variable (i.e.: one we can change directly, one the values of which we alter in order to modify the variables in given ratios with them). Similar problems arise in cases like using the length of a shadow and rules of optics to explain the height of a flagpole, but all such arguments fit the D-N model, and are thus explanatory according to Hempel.

Probability cases are perhaps the trickiest of all these criticisms. According to the D-N model,[v] cases of probability cannot be explanatory because the explanandum does not follow logically from the explanans. In the previous three criticisms, the D-N model was too permissive, including arguments we did not wish to classify as explanatory; probability cases expose the exclusive nature of D-N explanation, excluding factors we want to label as explanatory, or at least as explanatorily relevant. Again, let us illustrate the problem using an example:[vi]

Jim contracted the Epstein-Barr virus (EBV).

75% of people who contract the Epstein-Barr virus will contract mononucleosis (mono).

Therefore, Jim contracted mono.

The conclusion of the argument, the explanandum phenomenon, does not follow logically from the explanans, because the universal is probabilistic and does not lead unexceptionally from an antecedent to a single consequent. Looking at Hempel's four criteria, the explanans contains empirical data and the sentences of the explanans are true.[vii] The explanans does not contain a general law because the universal in this case, that 75% of people who contract EBV will contract mono, does not "assert general and unexceptional connections between specified characteristics,"[viii] which is a criterion for general laws. These are to be "distinguished from the so-called statistical laws [that] assert that in the long run, an explicitly stated percentage of all cases satisfying a given set of conditions are accompanied by an event of certain specified kind."[ix] Furthermore, because the universal in the explanans is not without exceptions, the argument is not valid, and therfore D-N model excludes this argument as an explanation. This exclusion is in order, as there is not a full explanation here for why Jim contracted mono. Why did he fall into the 75% and not into the 25%? The argument has no explanatory power because we cannot subsume the antecedent conditions under an unexceptional rule. Furthermore, we could not have predicted the outcome with certainty given this argument.

However, though we should not want to include this argument as an explanation, we should also not throw it out entirely. EBV is a prerequisite for mono, as contracting mono is impossible without first contracting EBV. A proper D-N explanation could run as follows:

Jim contracted mono.

It is impossible to contract mono without first contracting EBV.

Therefore, Jim previously contracted EBV.

This is an appropriate D-N explanation, but the explanation of contracting EBV is not what we are after here. Furthermore, contracting mono does not answer the question of why Jim contracted EBV, certainly not in any intuitive sense, and so though we can carry out the subsumption, the result is not the explanation we were hoping for. What we are after in this case is to express the explanatory relevance of EBV in the contracting of mono. EBV is insufficient to bring about mono, but it is a necessary precursor, and thus it would seem explanatorily relevant.

The modified D-N model

One of Hempel's four criteria is that the explanandum follow logically from the explanans, which is to say that for an argument to qualify as an explanation, "If [explanans], then [explanandum]," must be a true hypothetical statement. However, clearly we are not satisfied with all such explanations, as the tacking, irrelevance and asymmetry cases demonstrate. How, then, can we retain the general structure of the D-N model while eliminating these intuitively problematic explanations? Both tacking and irrelevance produce intuitive problems because they include elements in the explanation that we think should not be there, and one way to eliminate these elements is as follows: use "If *and only if* [explanans], then [explanandum]," as the modified hypothetical by which to judge putative explanations.

Let us assess how this modification can handle the tacking and irrelevance cases. Under Hempel's original model, we had to accept that "If hexed salt dissolves in water and Milo hexed the salt, then the salt dissolves," was an explanation for the dissolution of the salt. However, given the modified version we need not, because "If *and only if* hexed salt dissolves in water and Milo hexed the salt, then the salt dissolves," does not hold, then it cannot possibly be the explanation. A simple test will demonstrate that non-hexed salt will dissolve under the same conditions as hexed salt, and therefore the hexing is shown to be irrelevant. This irrelevance is flagged by the fact that it does not meet the modified D-N hypothetical.

In the tacking case, if the antecedent condition A can be subsumed under the general law B to derive the explanandum, then it can also be subsumed under the general law of the conjunction of B & C. That is to say, assuming that A and B are sufficient to derive the explanandum phenomenon to be explained, then the general law C can be tacked onto B and the same derivation holds. For Hempel, this was problematic. For the modified D-N model, assuming that "If and only if A and B, then [explanandum]," is true, then "If and only if A and B & C, then [explanandum]," is false. If A and B were sufficient on their own, then C cannot be a necessary condition of the explanation.

Hempel's model derives explanatory power from subsumption, which may seem unintuitive: after all, why does knowing that other bits of copper are conductive help me to understand that this piece is as well?[x] When one dissects Hempel's model, one realizes that it alludes to sufficient conditions under which the explanandum comes about, and this condition comes from the "if" component of the hypothetical. Explanations are meant to yield understanding, according to Hempel,[xi] and meant to characterize genuine relevance relations, according to Kitcher.[xii] I believe that understanding is specifically the appropriation of these relevance relations, and that relevance relations are the necessary and sufficient conditions for the bringing about of a phenomenon. Necessary and sufficient conditions should be helpful in several areas of this discussion. First, it suggests a research program that I take to be nicely in line with scientific practice. Second, it outlines an ideal for explanation: explanations ought to situate an antecedent condition with respect to certain necessary and sufficient conditions under which the explanandum phenomenon occurs. Third, as was already discussed, we can say that explanations grant us understanding of phenomena to be explained, which is in line with Hempel's and Kitcher's remarks. We can furthermore explicitly define understanding with respect to necessary and sufficient conditions. The complete explanation, then, is one that outlines the necessary and sufficient conditions for an explanandum, which is to say that it provides a true if-and-only-if statement (containing both empirical antecedents and general laws) as explanans, and leads to complete understanding.

Before coming back to these remarks, let us finish the discussion of the four criticisms leveled against Hempel. Next up is the asymmetry case. How does the duration of the period of a pendulum, in conjunction with the pendulum law, explain the length of its string? Explanations of this kind jar our intuitions because we can only modify the duration of the period by physically modifying the length of the string. However, I believe that the modified D-N model can sort us out. In Hempel's original model, explanation was meant to be an answer to the question "Why does the phenomenon occur? … [A]ccording to what general laws, and by virtue of what antecedent conditions does the phenomenon occur?"[xiii] Given the modification, the reformulated questions would be as follows: Why must the phenomenon occur? According to what general laws, and by virtue of what antecedent conditions must the resulting phenomenon be the case? In the pendulum example, why must it be the case that the length of the pendulum's string is 9.8 metres? Assuming that the duration of the period is 2π seconds, and that the pendulum law is true, the length could not be otherwise. The explanans presents an account of the necessary and sufficient conditions for the pendulum's length to be what it is.

The fourth criticism was about probability cases. Remember, from Jim's contracting EBV and the probability that 75% of people who contract EBV will contract mono, we could not derive the explanandum that Jim contracts mono. This type of explanation did not meet the criteria of Hempel's original model, which required only sufficient conditions, and so it will also not meet the criteria of the new model.

However, while we must concede that these facts alone do not explain Jim's contracting mono, we can say a little bit more on the subject. The criteria of the new model are such that explanations describe necessary and sufficient conditions, and while probabilistic explanations do not yield sufficient conditions, they certainly can yield necessary ones, as is the case with Jim contracting mono. As discussed earlier, had he not contracted EBV, he could not have contracted mono, and therefore EBV must be a necessary condition in the explanation of mono. The probabilistic argument yielded some important information, we have better understood the phenomenon to be explained (i.e.: have a better grasp of its necessary conditions), but we have not yet explained it (i.e.: given an account of necessary and sufficient conditions). Following the new question that explanations are supposed to answer: according to what general laws, and by virtue of what antecedent conditions must it be the case that Jim contracted mono? It need not be the case that Jim contracts mono, after all, only 75% of people who contract EBV will contract mono. But at the same time, we have improved our understanding of the phenomenon, which suggests that giving complete explanations is not our only way of doing so. Furthermore, Hempel's model not only excluded the probabilistic explanation, but explanations under his D-N model only yielded understanding of sufficient conditions, and thus the necessary component identified in our discussions here would have no place in that model.

The case of EBV and mono is probably not one of a purely probabilistic nature, as there is likely a reason that 75% of people who contract EBV will contract mono, and this explanation would follow a D-N structure. For example, suppose that people with EBV who come into contact with the mononucleosis virus will contract mononucleosis. Jim has EBV and came into contact with the mononucleosis virus; therefore, he contracted mono. Why do 75% of people with EBV contract mono? Because 75% of people with EBV come into contact with the mono virus. Why a given individual would fall into the 75% or the 25% can be explained by their contact or non-contact with the mono virus.

However, the case of quantum mechanics (QM) suggests that there is not always a D-N explanation that can be given for a specific individual case, one explaining why it falls within one statistical category as opposed to another. Philip Kitcher gives a full explanation of this in "A Defense of Deductive Chauvinism," the fifth section of his *Explanatory Unification and the Causal Structure of the World*.[xiv] Allow me to briefly go over some of his main points regarding QM. Kitcher distinguishes between ideal explanations *qua* the full deductive explanation of a given phenomenon, and *qua* the best explanation that the phenomenon permits us. We cannot give an ideal explanation of the first type for why $electron_1$ tunneled through, but we can give an explanation of the second type, which is to derive the relevant Schrödinger equation, and this derivation explains why we could not give an ideal explanation of the first type.[xv] The first type of explanation would answer the question "Why must it be the case that $electron_1$ tunneled through?" Assuming QM is correct, and that electrons being reflected or tunneling through really is simply a matter of statistical likelihood, we should not be able to answer the question of why it must be the case that $electron_1$ tunnels through. The derivation of Schrödinger equation explains why answer that why-question is impossible, and gives us the probabilities of tunneling through as opposed to being reflected. Deriving the Schrödinger equation yields understanding of the phenomenon: it presents the necessary and sufficient conditions for the electron's behaviour to have the probabilities that it does, and furthermore explains why there are no necessary nor sufficient conditions for it either tunneling through or being reflected.

Philosophical fallout

Allow me now to get back to the three consequences of pitching explanation as presentation of necessary and sufficient conditions. The research program suggested by this account seems to me in line with scientific practice. We witness a phenomenon and ask a why-question about it. Several hypotheses are put forward, each of which presents sufficient conditions, and through empirical testing we rule out those that present unnecessary conditions. Do we ever arrive at an end of science, is there a master theory that takes account of all necessary and sufficient conditions? And can we ever give *the definitive* explanation of a phenomenon, leading to complete understanding of it, rather than merely giving *an* explanation that yields partial understanding? I do not believe that such finality is possible in science, but my account is compatible with the both positions, either that there is an end to science or that there is not.

This research program, whether one believes there to be an end of science or not, certainly suggests an ideal for both science and explanation. The ideal of science is to provide explanations, and the ideal of explanations is to provide insight into necessary and sufficient conditions, which in turn contribute to our understanding of a given phenomenon. However, if there is no end to science, what can we say about current theories? It would be a great failure of any account of scientific explanation, I take it, to rule out all the explanations given by scientists claiming them to be non-explanatory. The ideal end of science would be a D-N explanation that reveals the necessary and sufficient conditions for a phenomenon. Science (at least currently) does not meet this ideal end, and it fails to do so in two respects: 1. Explanations given in science are (always) open to revision, and are therefore not conclusive; 2. Explanations in science do not always adhere strictly to the D-N model.

Here are the definitions I will use for the following terms: the truth of a theory is not temporally sensitive. We did not have true laws of nature before, and then they became false when we made new observations. If we have ruled out the possibility of the truth of a law, then it never was true to begin with. Hempel discusses this point in terms of law and law-likeness: "Strictly speaking, only true law-like statements can count as laws–one would hardly want to speak of false laws of nature."[xvi] Universals, or law-like statements to use Hempel's language, can be well supported or not well supported, and this variable is a function of how much testing they have undergone. In the course of testing, law-like statements can be confirmed false, or they can be made better supported, but given the nature of inference, I believe that no test can confirm its truth. Truth is defined as whether a universal really holds in an exception-less fashion, support for a given universal is how good our reason is for believing that the universal is true, and confirmation is the conclusive assessment of a universal's truth or falsity.

In the course of scientific research, we come up with several hypotheses about sufficient conditions for the phenomenon in question. We then carry out testing to determine which, if any, also discloses the necessary conditions. Supposing we eliminate all of our hypotheses, we confirm that they are all false, then it's back to the drawing board and the phenomenon has yet to be explained. In this case, we have still increased our understanding of the phenomenon all the same: we have narrowed in on certain sufficient conditions for its coming to pass, and have eliminated certain possible candidates for necessary conditions.

Supposing we eliminate all the possibilities but one, we arrive at an explanation. We do not have the definitive explanation, but we have a putative explanation, and we continue to test this hypothesis as well as using it in practical applications. The more we use it and the more resilient to falsification it proves itself to be through testing and applications, the better supported it is and the better supported the arguments are that implicate it in explaining phenomena. As our theories become better and better supported, they take on greater explanatory force: our understanding of the necessary and sufficient conditions for a phenomenon becomes greater and greater. When we confirm that a theory is true, and again I doubt this possibility, we have conclusively identified the necessary and sufficient conditions for a phenomenon; we can give the definitive explanation; we have fully understood the phenomenon.

In giving this characterization of scientific explanation, it is only too clear that actual scientists do not strictly adhere to a single and uniform practice in giving explanations. Scientists generally do not respond to why-questions by explicitly citing the full explanans from the D-N argument from which we can derive the explanandum phenomenon at issue. In daily parlance, few (if any) of us actually do this, but I believe that scientific explanations do imply this kind of underlying structure even though it is certainly far from explicit in certain cases.

I believe that what scientists are actually doing in giving explanations is, either implicitly or explicitly, citing the necessary and sufficient conditions for a phenomenon, and that these can always be re-arranged into a presentation in the formal structure of the modified D-N model. Let us take, for example, the tipping over of an inkpot on a desk. "Why did the inkpot tip over?" "Because I knocked my knee against the desk." We can safely assume that this putative explanation of the phenomenon is claiming the necessity of hitting the desk with one's knee. After all, if hitting the knee against the desk were not a necessary component of the explanation, why would it be cited at all? Remember that this is exactly the problem we had with Milo hexing the salt: we do not want to accept Milo's hexing as explanatory because it is not necessary to the process of dissolution. So, too, would we feel the same way about the knee hitting the desk. If it were not believed to be a necessary component of the explanation, we would take it to be irrelevant and therefore not cite it in trying to explain the tipping of the inkpot. Thus, we have identified the implicit condition of necessity in the example.

"Why did the inkpot tip over?" Responding with the answer "Because I knocked my knee against the desk," suggests that knocking the desk was a necessary component in the explanation. If it were not necessary, I would not cite it in answering the question. In the same way, if it were not sufficient, I would not cite *only* it in answering the question. It is assumed that because I do not continue, that I do not go on to explain what else happened, that the reason I have cited is sufficient to explain the phenomenon.

Of course, there is more information given in this explanation than merely what is explicitly stated. There is a whole context of beliefs we take for granted in communication, and some of these will be relevant to fill out the necessary and sufficient conditions. It is likely not implicit that *any* contact between the knee and the desk would have resulted in the tipping over of the inkpot, but rather that the inkpot tipped over because I hit my knee against the desk *hard enough to tip the inkpot*.

Once the necessary and sufficient conditions are identified, it is just a matter of reformulating the explanation to fit the model. The same applies to most arguments: we do not always explicitly identify premises and conclusions as such, and certain premises are understood and therefore not explicitly mentioned, but nevertheless all these elements are there, and we have no problem speaking of giving arguments when these elements are not explicitly demarcated. How, then, can we reformulate the present example to fit the model?

The inkpot was sitting upright on the desk.

If the desk is hit hard enough (to tip the inkpot), then the inkpot will turn over.

My knee hit the desk hard enough to tip the inkpot.

Therefore, the inkpot turned over.

Not all of this information appears explicitly in the informal explanation, but none of it is a far stretch from what is implied thereby. This reformulation is not a very rigorous scientific explanation, but no more nor less rigorous than the informal explanation of which it is a reformulation, and this is as it should be. It can still be considered explanatory because it fits the model: it contains an explanans composed of antecedent conditions and a general law, the explanans is true, and the explanandum follows logically therefrom. Furthermore, the additional "If and only if [explanans], then [explanandum]," also holds. The explanation might be rejected by Hempel because it does not follow the formal D-N argument structure. However, I believe that it implicitly does present (the explanation as) a sufficient condition, and therefore could be rearranged into the D-N form. Furthermore, I believe it also implies that the explanation is a necessary condition. The informal explanation can be represented as fitting my modified D-N model because it presents both necessary and sufficient conditions, and it therefore yields understanding of the phenomenon in those terms, albeit in only a very shallow understanding as the predicate "hard enough to turn the inkpot" is very imprecise. But let us spill no more ink on this example.

Conclusion

The modification of Hempel's model makes the model more strict, giving us a systematic way to eliminate putative explanations that critics accused Hempel of admitting. The logical move to the if-and-only-if criterion was also accompanied by a subtle shift in the philosophical backdrop underlying explanations in science. Their function is to yield understanding, specifically the understanding of both necessary and sufficient conditions for phenomena, and they are answers to slightly different why-questions than Hempel maintained. The shift in why-questions removes the intuitive clash in asymmetry cases, and the clear demand for necessary and sufficient conditions gives reason to support Kitcher's deductive chauvinism. Furthemore, even in QM cases, deductive derivations of the relevant Schrödinger equations shows *why* there are no necessary or sufficient conditions for a given phenomenon to fall in one indeterministic category of probability rather than another.

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[i] [Hempel, 1965: 245]
[ii] This essay is concerned with explanation in the natural sciences, and therefore any reference to explanation *simpliciter* will refer to explanation in the context of natural science.
[iii] [Hempel, 1965: 246]
[iv] This example brings up another set of problems, which is the role of models in explanation. These issues will not be dealt with in this paper, but for discussion concerning modeling, idealization and the "in principle" corrigibility of models, see [Wayne 2010].
[v] In cases of probability, Hempel proposed using a completely different model, the inductive-statistical (I-S) model, but let us stick to D-N models for now. The modification I will introduce later in the paper will justify sticking with the D-N model here, because the modified model will get us where I believe we want to go.
[vi] The commonly used example in these discussions is the development of paresis in patients with latent syphilis. However, as I am more familiar with the actual mechanics of mononucleosis and the Epstein-Barr virus, I decided to present this case as my example. My arguments about this example should be applicable to discussion of paresis found in discussions of the D-N model.
[vii] Or at least they could be. In this case, they are not, as I simply concocted the figures randomly, but for the purpose of the argument I consider this fact to be irrelevant.
[viii] [Hempel, 1965: 250]
[ix] [Hempel, 1965: 250]
[x] I am (once again) indebted to Calvin Normore for raising this concern.
[xi] [Hempel, 1965: 345]
[xii] [Kitcher, 1989: 417]
[xiii] [Hempel, 1965: 246]
[xiv] [Kitcher, 1989: 448-459]
[xv] [Kitcher, 1989: 451]
[xvi] [Hempel, 1965: 338]