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Scientific Explanation: The Causes, Some of the Causes, and Nothing But the Causes

1. Introduction

It would be desirable for philosophical accounts of explanation to capture the type of scientific explanation which is exemplified by this case:

In 1981 physicians in Los Angeles and New York began to notice an unusual cluster of cases of formerly rare symptoms—Kaposi's sarcoma, *Pneumocystis carinii* pneumonia, and other opportunistic infections, primarily in young men.[1] Faced with this phenomenon the physicians asked in each case "What is the explanation of this man's illness?"[2] and about the cluster itself "What is the explanation of the multiple incidence of these symptoms?" Because of the absence at that time of any known causes, the response to each question was to begin a systematic search for an explanation. What the investigators were searching for was not an argument or a speech act or a set of sentences, it was a real thing, a cause of the sickness. As we now know, an explanation was found, which was, among other things, a group of retroviruses that cause AIDS. This discovery was made possible only through the systematic use of scientific methodology, involving epidemiology to identify risk groups, theories in molecular biology to identify possible causal factors, and controlled experimentation to isolate specific causal factors which were responsible in each case. Subsequently, and only subsequent to this discovery, were the investigators in a position to answer why-questions, and to gradually fill in the causal story so that groups with different interests—homosexuals, intravenous drug users, public health officials, biomedical researchers, and so on—could be given the parts of the explanatory story in which they were most interested. Most notably, an explanation could be given even though it was incomplete. It was not claimed that there were no other causal factors involved, factors which increased or decreased the risk for an individual, only that a part of the causal mechanism leading to the illness in each case had been found, and a mechanism of transmission found which was causing the cluster.

This activity of searching for and discovering an explanation of a given effect is something which, although not exclusive to scientific research,[3] is a sufficiently important feature of scientific activity that special methods have been developed to isolate such discoveries. These methods may be experimental, they may use statistical surrogates for experimental controls, or they may use theoretical idealizations to mimic such controls. Which method is used will depend upon a complex of conditions, involving the nature of the subject matter, the state of scientific and technological knowledge, ethical constraints, and so on. In each case, however, the emphasis is on isolating causal factors, structures, and mechanisms whose operation may be taken to partially constitute the explanation of the phenomenon at hand. There is also no denying that linguistic explanations are required for conveying this information beyond the point of discovery. So what is the relation between these two quite different uses of the term 'explanation'? It is clear that the first sense, the objective sense in which one can discover explanations, is intimately linked with causation, so closely linked in fact that some writers have wanted to deny that our first sense is in fact a genuine kind of explanation, sometimes because explanations are supposed to generate intensional contexts, whereas causes plausibly do not; sometimes because explanations might have inescapably pragmatic aspects, whereas causes do not; sometimes because the logico-linguistic forms of natural language representations of explanation seem to be different from those of causal claims. Such views tend, I think, to evolve from a philosophical strategy which takes explanatory discourse as a given, a storehouse of factual information about explanations which, after philosophical analysis, will yield the correct form for explanations.[4] Within this approach the logical structure of linguistic explanations is taken as primary, and causal explanations, where applicable, have to conform as a special case to the general logical structure.

I believe that it is worth employing a different kind of strategy. It is significant that most of the counterexamples to Hempel's deductive-nomological and inductive-statistical models of explanation hinge on those models' inability to correctly capture causal relationships.[5] In addition, a significant body of work on the nature of causal relata has exposed difficulties inherent in descriptive representations of events, which suggests that an adequate account of causal relations must involve some direct representation of the causal relata.[6] Increased understanding of probabilistic causality has made it clearer how causal explanations for undetermined effects might be given.[7] And a revival of interest in the role played by experimentation in science tends to make one aware of the limitations imposed by purely logical analyses of causal structure.[8] These considerations lead me to take our project as a synthetic one: it is to see how the analytic methods of science discover the structural form of causal explanations of phenomena, and then to construct an appropriate linguistic representation which faithfully preserves that structure.

Our task is thus a restricted one. It is to provide an account of the nature of singular causal explanations.[9] In various places I shall emphasize the role played by probabilistic causality in explanations, but the framework is designed to apply to non-probabilistic cases as well. Indeed, by examining the similarities between probabilistic causality and causal relations holding among quantitative properties, the probabilistic case can be seen to be rather less idiosyncratic than it first appears.

2. The Multiplicity, Diversity, and Incompleteness of Causal Explanations

We begin by noting that science is called upon to find explanations for phenomena originating in widely differing circumstances. It does best when explaining phenomena produced by science itself in the clean and austere conditions of the laboratory, when there is ordinarily only a single causal factor operating and the law governing the phenomenon is already known. But science is frequently called upon to find the explanation of naturally occurring phenomena such as epidemics, tree diseases, rainfall distributions, migratory patterns, rainbows, the nonexistence of higher forms of life on Mars, and planetary movements. It is also often required to explain the results of applied science, such as rocket explosions, holes in the ozone layer, the properties of artificial elements, the effect of plastics on the environment, and presidential campaigns.

A characteristic feature of these natural and unnatural phenomena is that they are usually the result of multiple separable causal influences. For example, the rate of enzyme-catalyzed reactions is affected by the enzyme concentration, the substrate concentration, the temperature, the pH of the substrate, oxidation of the sulfhydryl groups of an enzyme, and high-energy radiation; the first two increasing the rate of reaction, the last decreasing it, while the actions of the third and fourth have maximal points of inflexion at optimal temperature and pH, respectively.[10] Multiple—because except in specially constructed artificial settings each of these factors will be causally effective in a given reaction. Separable—because the experimental and theoretical devices mentioned earlier enable one to isolate the effects of a single factor. Causal—if they satisfy the invariance requirements of §4 below, where it will be argued that if they do, then we may infer not only that the causes are separable but that they are in fact operating separately.

It then follows that to properly convey the structure of the causal origins of a given phenomenon, a linguistic explanation should preserve the separation between distinct and independent causal influences on that phenomenon. And so we have the first constraint on representations of causal explanations: they must correctly represent the *multiplicity and separateness* of causal influences on a given phenomenon.[11]

Let us now examine a second characteristic of causation. It is by now generally agreed that there are two distinct kinds of probabilistic cause, which I shall call "contributing" and "counteracting."[12] Consider first a simple example.

The bubonic plague bacillus (*Yersinia pestis*) will, if left to develop unchecked in a human, produce death in between 50 and 90 percent of cases. It is treatable with antibiotics such as tetracycline, which reduce the chance of mortality to between 5 and 10 percent.[13] The causal mechanisms involved, the mode of transmission, and the action of the treatment on the infected human are sufficiently well established that there is no doubt that infection with *Yersinia pestis* is a contributing cause of death in a human, and administration of appropriate antibiotic treatment is a counteracting cause of death. It is also true that the contributing cause is not sufficient for death, and that the counteracting cause does not guarantee recovery, as the cited probabilities show. Now suppose that Albert has died, and we ask for an explanation of this event. Once again, it is imperative to separate the different causal influences on the effect to be explained, the reason this time being the diversity of types of cause, rather than mere multiplicity. To do that we shall need to use a new explanatory format. Historically, the standard format for explanations has always been the simple 'Y because X' mode, but one of the striking features of explanations involving contributing and counteracting causes is that this historical format is quite inappropriate. It is absurd to claim that "Albert's death occurred because of infection by the plague bacillus and the administration of tetracyclin." Instead, an appropriate response at the elementary level would be "Albert's death occurred because of his infection with the plague bacillus, despite the administration of tetracycline to him." Thus the second constraint on explanations is: they must correctly represent, where appropriate, the *diversity* of causal influences on a phenomenon.

The third characteristic feature of causal explanations, which this time is epistemic in flavor, is the incompleteness of many of our explanations of causally produced phenomena. Given the multiplicity and diversity of causal influences, it will be rare that we are in a position to provide a complete list of all the influences which affected a given outcome. In both the AIDS example and the enzyme-catalyst example, there is no pretence that a complete explanation has been discovered. Yet we have good reason to suppose that what has been offered as an explanation is true, and if it is, then the incomplete explanation can be partially complemented by successive discoveries which add to our understanding without undermining the accuracy of the previous accounts. Thus the third constraint on linguistic explanations is that they must be able to provide *true yet incomplete* representations of causal explanations.

3. The Canonical Form for Causal Explanations

Here, then, is a linguistic mode for providing explanatory information in the case of specific events which explicitly provides for each of the three features discussed above. If one wishes to request an explanation, the canonical form will be "What is the explanation of Y in S at t?"[14] An appropriate explanation will be "Y in S at t [occurred, was present] because of Φ, despite Ψ" where 'Y', 'S', 't' are terms referring to, respectively, a property or change in property, a system, and a time; 'Φ' is a (nonempty) list of terms referring to contributing causes of Y; and 'Ψ' is a (possibly empty) list of terms referring to counteracting causes of Y.

The explanation itself consists in the causes to which 'Φ' jointly refers. Ψ is not a part of the explanation of Y proper. The role it plays is to give us a clearer notion of how the members of Φ actually brought about Y—whether they did it unopposed, or whether they had to overcome causal opposition in doing so. Thus Ψ may be empty, in which case we have an explanation involving only contributing causes to Y's occurrence, but if Φ is empty (while Ψ is not), then we have no explanation of Y's occurrence, merely a list of factors which lessened the chance of Y's occurring.[15]

We have already seen an elementary application of this format to the plague case. A somewhat more sophisticated example involves the case of enzyme catalyzed reactions mentioned earlier. Thus, if the phenomenon to be explained is an increase in the reaction velocity of a metabolic process, we can assert (omitting references to the system and time) "the increase in reaction velocity occurred because of the increases in enzyme and substrate concentration to optimality, despite the increasing oxidation of the dehydrogenases and irradiation by ultraviolet light." (I note here in anticipation of a later claim that although each of the explanations discussed so far involve phenomena which are plausibly not determined by the cited factors, there is no mention of probability values in their explanations.)

Although I have stressed the way in which probabilistic causality makes us aware of the need for a new explanatory mode, such explanations are also possible for phenomena which we have every reason to suppose are deterministic in character. For instance, in theoretical representations of the value of the angular momentum of the earth, the simplest model treats the sun as fixed. Then, to a good approximation the angular momentum of the earth is constant, and its value is given by the relevant conservation law. But this idealized picture is too simple, and a number of small but important causal influences have to be considered to explain the actual motion of the earth. First, the earth is an oblate spheroid rather than a sphere, and this produces a precession in the orbital plane of the moon, which in turn produces a precession in the earth's angular momentum. Second, tidal friction gradually slows the earth's rotation owing to a couple acting on the equitorial tidal bulges. Third, there are thermodynamical "tides" in the earth's atmosphere owing to periodic heating by the sun, with a consequent gravitational couple from the sun which acts to speed up the earth's rotation. Fourth, the nonuniformity of the sun's gravitational field results in an additional precession of the earth's angular momentum.[16]

Consider how we should respond to a request for an explanation of the increase in angular momentum of the earth over the conserved value. The explanation would be "because of the precession of the moon's orbital plane, the nonuniformity of the sun's gravitational field, and the action of thermodynamical tides, despite the slowing effects of tidal friction." It is important to note that these explanations can be given even though they are incomplete. There is no pretense that all causal factors affecting the angular momentum of the earth have been cited. The omissions are not due to the scientist selecting those factors which interest his listener, or to being constrained by the form of the request for an explanation. It is because there are many influences on the earth's rotation beyond those cited, most of which are as yet unknown. The geophysicist knows that there exist these unknown causal factors, yet the factors cited do provide an explanation, however incomplete, of the explanandum. Nevertheless, the explanation given is true. Every factor cited is a cause of the increase in the earth's angular momentum, and the explanation correctly classifies them into contributing and counteracting causes. (The reason why we can extend this terminology of contributing and counteracting causes beyond the probabilistic realm is given in the next section.)

This example is characteristic of many scientific investigations, both theoretical and experimental. In the theoretical realm, corrections to the ideal gas laws owing to intermolecular forces (by means of virial coefficients), the elaboration of four variable causal models in sociology to five variable models, and time-independent perturbation theory for representing the Coulomb repulsion between electrons in multi-electron atoms all use this cumulative approach to explanation. Sometimes the cumulative filling-in is made via the intermediate device of theoretical models, when influences which have been known about and deliberately omitted for the sake of simplicity are added to refine the model, or to introduce a student to a higher level of sophistication in the explanatory account. The experimental case deserves an essay in its own right: suffice it to say here that one of the principal uses of the experimental method is for causal discovery, confirmation and testing, ordinarily of causal relations which have been singled out from the set of multiple influences by means of controls, randomization, or statistical surrogates such as multiple regression analysis.

4. Ontology

Scientific analysis separates causal influences, and our representations must preserve this separation. So events cannot be identified with spatio-temporal regions[17] because any given spatio-temporal region ordinarily contains many properties and changes, some of them causally relevant to a given effect, many of them not, and those that are relevant may be of different types. For example, the spatio-temporal region containing an increase in temperature from 20°C to 800°C of a sample of magnesium also may contain a change in color and length of the bunsen flame, a change in the sound emitted by the bunsen, a change in the volume of the magnesium sample, the presence of oxygen, the lack of an oxidized layer on the magnesium and so on, each of these factors save the first and last two being causally irrelevant to the effect, which here is the ignition of the magnesium. A similar remark may be made about the spatio-temporal region containing the effect, which also contains numerous irrelevant features including the spatio-temporal location of the effect, the manufacturer's brand name stamped on the sample, the property of being held by Paul Humphreys, and so on.

In our construal of causal explanations I employed this ontology: An event is *the possession of, or change in, a property of a system on a given occasion* (trial). Events are thus taken as concrete, specific entities, actual instantiations of or changes in worldly properties of a system, these properties being possessed by specific structures, themselves a part of the world, with these structures persisting through the change in properties which constitute an event. (For simplicity I restrict myself to monadic properties. Events involving relational properties may be dealt with analogously.)

This approach could be adopted simply on the grounds that it enables us to maintain a separation between causal factors in the desired way. There is, however, a more systematic justification underlying this choice of ontology which I should like to draw out here.[18] In his *System of Logic* Mill argued that the distinguishing feature of a genuine cause was its unconditionalness. Succinctly, for X to be a genuine cause of Y on a given occasion, it must be true that X causes Y whatever other circumstances prevail, for if not, then it is not X *simpliciter* that caused Y on that occasion, but X together with some further factor(s) Z, the presence or absence of which, in combination with X, results in Y appearing on that occasion, but the absence or presence of which, on other occasions, leads to Y's nonoccurrences. This means, of course, that any singular causal claim is also implicitly general. But in what relation does the singular causal sequence stand to the universal causal law? Is the singular sequence causal because it is an instance of the primary universal law, as regularity theorists would maintain, or is the general law nothing more than a collection of singular causal sequences? By considering these two options we can see why permanent structures are required for our ontology, what the correct account of probabilistic causality is, and why it is appropriate to extend the contributing and counteracting causal terminology outside the probabilistic realm.

Regularity theorists require that for an event sequence to count as causal it must be an instance of a universal regularity. But as has often been noted, there are few, if any, observed universal regularities under which singular events can fall. The natural world as observed is simply too chaotic a place for that. However, as Bhaskar (1975) noted, the creation of experimental contexts in the natural world results in just those kinds of regularities which are needed for laws by a regularity theorist. The problem is that these regularities disappear once the experimental controls are lifted. Hence if causal laws are identified with observed universal regularities, and singular event sequences are causal only if instances of causal laws, then singular phenomena occurring outside experimental contexts will rarely, if ever, have causes or causal explanations. (I note in passing that this is a serious problem for any model of explanation which requires deductive subsumption under such regularities.)

There are various ways one might escape this conclusion. To avoid repetition, I refer the reader at this point to my (1988) for detailed arguments on those options, and merely state the conclusion of that paper here: the only plausible account of causation which retains universality and allows causal explanations of singular phenomena in nonexperimental contexts is one which refrains from identifying causal laws with sequences of observed events, but instead allows for the existence of permanent or semi-permanent structures persisting through the creation and destruction of the experimental contents which give rise to whatever regularities are observed. It is important to emphasize that none of the arguments which lead to this conclusion should be unacceptable to an empiricist unless he denies the need for an explanation of the difference between experimental and nonexperimental contexts and rejects *a priori* any entity which does not satisfy a fixed, atemporal criterion of observability. For experimentation is undeniably a central feature of scientific empiricism, and many structures initially discovered in such contexts are later found to persist outside them as well.

I now have to make one unargued assumption to carry the case into the probabilistic realm. It is that there are such things as physical chances grounded in structural features of an indeterministic system. Although I believe that it is possible to extend the above argument to establish the existence of such structural probabilities, one has to make a further explanatory inference from observed relative frequencies to constant physical probabilities as generating conditions of those frequencies, and it is not clear to me under exactly what circumstances this inference is legitimate. Hence I rely on this intuitive picture: physical probabilities are dispositional properties, alterations in the structural basis or in the conditioning variables of which result in an alteration of the associated probability distribution. We can now see how to apply Mill's invariance condition to the probabilistic case. Recall that the characteristic feature of a probabilistic contributing cause was that it raises the chance of the effect, i.e., *it produces an increase in the value of the chance of the effect*. So, assuming the existence of physical chances, the *direct* effect of a contributing cause is an increase in the chance (of some property). But this is no different from any familiar and uncontroversial case of sufficient quantitative causation. Increase the voltage in a wire of a fixed resistance and the effect is an increase in the value of the amperage. Increase the intensity of a classical radiation field on a particle and the effect is an increase in the chance of the induced emission of a quantum of e.m. radiation. This enables us to see why it is possible to naturally apply the contributing cause terminology both to deterministic cases such as the angular momentum of the earth and to probabilistic cases such as the bubonic plague. In both cases a contributing cause increases the value of a quantitative variable—it just happens that in the probabilistic case the variable is the value of the chance.

The application of this approach to the qualitative case is, I believe, quite straightforward, but cases where quantitative variables are specified exactly need some discussion. I shall deal with the deterministic case here, because the examples are clearer. Consider an individual who acquires an extreme fondness for chocolate and who tries to lose weight by taking diuretic pills. The chocolate intake produces an increase of 10 pounds of fat over the level the individual had without the chocolate input. The diuretic pills produce a decrease of 5 pounds of water compared with the weight level the individual had before taking the pills. The net *observed* increase in weight is 5 pounds, but in this case both the contributing and counteracting causes had their full effect. One could actually collect the increased fat and the lost water if one so desired. Thus, not only are the causes operating separately, they produce clearly separable effects which together produce the effect to be explained. Thus it seems appropriate to assert in the qualitative case "the increase in John's weight occurred because of the chocolate's caloric content, despite the diuretic action of the pills." Now consider a case where the contributing and counteracting causes produce their effects through mechanisms that are not so easily separable; for example, when fat is burned off by exercising. Is there any essential difference between this case and the previous one? Suppose that the fat was first put on and then part of it burned off by running. Then there would be no difference between the first situation and this one, and our explanatory form could still be used. How about the case where the chocolate input and the running occur together? Recalling our characterization of an invariant cause, if one reduces the exercise level to zero, the individual will not lose 5 pounds, and if one reduces the chocolate intake to zero, the individual will not gain 10 pounds, in each case compared to the situation with the putative cause present and all other factors as they are. Hence each influence was operating on the system during the trial and each played its role in the way the effect came about. And so "the increase in John's weight occurred because of the chocolate's caloric input, despite the burning off of fat by running" is also correct.

These are all cases where the causes and the effects are taken to have only qualitative properties, and there is little doubt that the approach works well there. The quantitative case, it turns out, is not so transparent, in that ordinary use appears to allow two different representations, the traditional "because" account and the mode suggested here. To decide between them we again need to look at the causal mechanisms underlying the observed phenomenon. Consider a room which is both heated and air-conditioned, and suppose that the temperature rises by 5°C (compared to the situation where neither is operating). Alone the heater would raise the temperature by 10°C; alone the air-conditioning would lower it by 5°C. Again, the qualitative case appears to work: "The temperature of the room rose because of the input from the heater, despite the cooling of the air conditioner." The mixed cases where either the effect is quantified or the causes are quantified, but not both, also seems to fit this pattern. Now consider these two claims:

(1) The increase of 5°C in the temperature of the room occurred because of the input of 10,000 Btu from the heater, despite the extraction of 5,000 Btu by the air conditioning.
(2) The increase of 5°C in the temperature of the room occurred because of the input of 10,000 Btu from the heater and the extraction of 5000 Btu by the air conditioning.

Prima facie, (2) seems more plausible than does (1). Why is this? There are, in fact, two aspects of the explanandum event that need to be explained: the increase in the temperature and the exact value of that increase. Emphasize the former and (1) will have some appeal; emphasize the latter and the superiority of (2) is evident. That (2) was preferable on first inspection is accounted for, I believe, by an entirely justifiable tendency to prefer precise, quantitative, explananda to imprecise, qualitative, explananda within scientific contexts. What does this example show us about our canonical form for causal explanations? Two things, I think. The first point, which I have already discussed and have more to say about in §6, is that it must always be clearly specified which aspect of a spatiotemporal event is the object of an explanation, so that ambiguities can be avoided. The second point is more important. In any deterministic explanation in which the explanandum is the value of a quantitative variable, all causally relevant factors will contribute to the system's having that exact value and hence the traditional 'because' format will be the appropriate one. In contrast, where the causal factors are only probabilistically related to the explanandum, what is crucial are increases and decreases in the chance of that explanandum, even in cases where the explanandum is itself quantitative in form. Consequently, the canonical format for explanations described earlier will frequently need to be used because of the presence of counteracting factors. This difference between the deterministic and the indeterministic cases explains why the inadequacy of the traditional 'because' format is not revealed within a very broad class of deterministic cases. (The reader will have noted that my earlier example involving the earth's angular momentum involved an increase in its value rather than the value itself.) The deficiencies appear only within the domain of qualitative deterministic explanations and qualitative or quantitative indeterministic explanation. This is not to say that the canonical format is the wrong one for quantitative deterministic explanations.

It is simply that the 'despite' clause is not used because of the absence of counteracting causes.

This argument rests on the claim that the precise value of the probability is not something that is involved in explanations of stochastic phenomena. The next section is devoted to establishing this claim.

5. Why Probability Values Are Not Explanatory

We have seen the role played in explanations by the multiplicity, diversity, and epistemic incompleteness of causes. We are now in a position to argue for a fourth thesis—that probabilities have no explanatory role. Let us begin by noting that every other contemporary account of probabilistic or statistical explanation requires that a probability value be cited as an essential part of the explanation of phenomena whose occurrence is, or is taken to be, properly stochastic in nature.[19] The most common reason for this is that they are all versions of a covering law model of explanation, and the covering law is a probability law (i.e., a law which assigns a probability value to the explanandum, either absolutely, or conditionally, or relationally). Because it is standardly required that all the elements of the explanans must be true, the probability law, being part of the explanans, must satisfy this requirement, and hence the true probability must be assigned to the explanandum by virtue of falling under this true covering law.[20]

This consequence, that an essential part of a probabilistic explanation is the attribution of a true probability value, must be rejected. The reasons are twofold. First, the insistence on specifying probability values makes it impossible to separate true explanations from complete explanations, with the dire consequence that it is rare, if ever, that we can in fact provide such an explanation. The situation is clearest if one considers explanations of specific outcomes, with the probability temporarily interpreted as a relative frequency, rather than as a propensity as I prefer. To attribute the correct probability to the explanandum in this situation, the problem of the single case must be solved: that is, the probability attributed to the explanandum must be the appropriate one for that particular case. All such solutions employ essentially the same device—a requirement that all (and only) factors which are probabilistically relevant to the outcome should be used to determine the class or sequence within which the relative frequency is calculated. Omit even one probabilistically relevant factor and a false attribution of probability will be made. To revert to an example I have used elsewhere, if an individual dies from lung cancer, having been a heavy smoker, omitting from the explanation the following probabilistically (and causally) relevant factors will result in a false probability value being given and hence, within the frameworks I am criticizing, a false explanation being given: (i) cosmic radiation from α-Centauri, (ii) a hereditary characteristic inherited from his great-great-grandfather, (iii) particles from a smokestack in Salem, Oregon. Because this completeness condition for probabilistically relevant factors, which surfaces in different ways in maximal specificity conditions, objective homogeneity conditions, and randomness requirements, cannot be separated from the truth conditions for the probability covering law when it is applied to single case explanations, explanations which require the true probability value to be cited cannot omit even absurdly small probabilistically relevant factors and remain true.

In contrast, if one holds that it is causally relevant factors which are explanatory, where a factor is causally relevant if it invariantly changes the propensity for an outcome, i.e., a change in the factor results in a differential change in the propensity irrespective of what other changes or conditions are also present, then specification of one or some of the causally relevant factors will allow a partial yet true explanation even in cases where the other factors are not known and the true probability value cannot be calculated. This distinction between true and complete accounts is similar to the distinction which has been common in English law for centuries between the truth and the whole truth. Of course, there everything is epistemically relativized, whereas the contrast here is between the truth and the complete truth. So we might say that for linguistic explanations we require the truth, nothing but the truth, yet not the whole truth, where for causal explanations this means citing the causes, nothing but the causes, yet not all the causes. Second, and consequently, this approach has the advantage that when a complete explanation is available, i.e., all causally relevant factors have been specified, then a specification of the true propensity or correct reference class is automatically given by the constituents of the Φ and Ψ elements of the explanation (although the probability value may not be calculable from this information, because there is no guarantee that all such values are theoretically computable). This fact that probability values are epiphenomena of complete causal explanations indicates that those values have themselves no explanatory power, because after all the causal factors have been cited, all that is left is a value of sheer chance, and chance alone explains nothing.

This position has a number of immediate consequences. First, it follows that there can be more than one true explanation of a given fact, when different sets of contributing and counteracting causes are cited. This feature of explanations involving multiple factors, while tacitly recognized by many, is equally often ignored in the sometimes acrimonious disputes in social and historical explanations. Very often, a plausible case can be made that a number of supposedly competing explanations of, for example, why the Confederate States lost the Civil War, are all true. The dispute is actually about which of the factors cited was causally most influential, given that all were present, and not about which of them alone is correct.

Second, our account enables us to distinguish between cases where a phenomenon is covered by a probability distribution which is *pure*, i.e., within which no parameters appear which are causally relevant to that distribution (more properly, to the structure to which the distribution applies), and cases where the distribution is affected by such parameters.[21] There is good reason to believe that the traditional resistance to allowing explanations of indeterminate phenomena arose from a naïve belief that all such phenomena were the result of purely spontaneous processes which were covered by pure distributions. While sympathizing with the intent behind this resistance, because as we have argued, pure chance explains nothing, we have also seen an important difference between situations in which the pure chance remains at the end of a comprehensive causal explanation, and situations in which pure chance is all that there is.

Third, the traditional maximal specificity requirements which are imposed on explanations to arrive at a unique probability value must be replaced by the requirement of causal invariance described earlier.[22] This invariance requirement is strictly weaker than maximal specificity because the presence of a second factor can change the propensity for a given factor to produce an effect, without thereby changing that given factor from a contributing cause to a counteracting cause, or vice versa, whereas if the second factor confounds a putative contributing cause and changes it to a counteracting cause, a change in the propensity must accompany this. Of course, epistemically, we can never know for certain that such confounding factors do not exist, but that is an entirely separate matter, although regrettably relative frequentists have often failed to separate epistemic aspects of probabilistic causality from ontic aspects. This rejection of the explanatory value of probabilities is the reason I called my causal account one of "aleatory explanations." This was to avoid any reference to "probabilistic explanations" or "statistical explanations," while still wanting to convey the view that causal explanations are applicable within the realm of chancy, or aleatory, phenomena. It is, perhaps, not ideal terminology, but it serves its intended purpose.

Fourth, aleatory explanations still require laws to ground explanations, but reference to these laws does not appear directly in the explanations themselves, and they are not *covering* laws. The role that the causal laws play here is as part of the truth conditions for the explanatory statement. For something to be a cause, it must invariantly produce its effect, hence there is always a universal law connecting cause and effect. The existence of such a law is therefore required for something to truly be a cause, but the law need only be referred to if it is questioned whether the explanatory material is true. I want to avoid the terminology of "covering laws," however, because the term "covering" carries implications of completeness, which is quite at odds with the approach taken here.

Fifth, there is no symmetry between predictions and explanations. As is well known, the identity of logical form between explanations and predictions within Hempel's inferential account of explanation initially led him to assert that every adequate explanation should be able to serve as a prediction, and vice versa. What we have characterized as causal counterexamples led him to drop the requirement that all predictions must be able to serve as explanations. Arguments due primarily to Wesley Salmon were influential in persuading many philosophers that we can explain without being able to predict. That independence of prediction and explanation is preserved here. We have seen that probability values play no role in the truth of explanations; *a fortiori* neither do high probability values. It is true that we need changes in propensity values to assess degrees of contribution, but even a large contributing cause need not result in a high relative frequency of the effect, for it may often be counteracted by an effective counteracting cause. Thus, as noted earlier, the plague bacillus contributes greatly to an individual's propensity to die, yet the counteracting influence of tetracycline reduces the relative frequency of death to less than 10 percent. It is also worth noting that predictions differ from explanations in that when we have perfect predictive power (a set of sufficient conditions) there is no sense in asking for a better prediction, but perfect sense can be made of giving a better explanation, i.e., a deeper one. The same thing holds for probabilistic predictions. When maximal specificity conditions have been satisfied, there does not exist a better prediction, but again better explanations may exist.

Sixth, aleatory explanations are conjunctive. By imposing the causal invariance condition, we ensure that there are no defeating conditions which turn a contributing cause into a counteracting cause, or vice versa, or which neutralize a cause of either kind. Thus, two partial explanations of E can be conjoined and the joint explanation will be an explanation also, indeed a better explanation by the following criteria: If $\Phi \subset \Phi'$ and $\Psi = \Psi'$, then the explanation of Y by Φ' is superior to that given by Φ. If $\Phi = \Phi'$ and $\Psi \subset \Psi'$ then again Φ gives a superior explanation, in the sense that the account is more complete.[23]

6. Why Ask Why-Questions?

We have seen how to present causal information so that its diversity and multiplicity is properly represented, and if the information is given in response to a request for an explanation, how that request can be formulated. It might seem that there are other, equally appropriate ways of presenting that information and of requesting it. For example, it appears that we might have used instead the form "X because Φ even though Ψ" as in "This individual died because he was exposed to the plague bacillus, even though he was given tetracycline," where X, Φ, and Ψ are sentences describing causes rather than terms referring to them.[24] And, rather than our "What is the explanation of X?," many would prefer "Why is it the case that p?," where again, in the latter, a propositional entity, rather than a term, provides the content of the question.[25] Does anything hinge on our choice of representation, or is it simply a matter of convenience which one we choose?

I believe that it does matter which choice we make. It has become increasingly common to take the why-question format as a standard for formulating explanatory requests. Accompanying this has been an increased emphasis on the need for including pragmatic factors in explanatory contexts. The two are, I think, connected, and because pragmatics have no place in the kind of objective explanations with which I am concerned, linguistic devices which require their introduction ought to be avoided.

Let me begin with three major claims which Hempel made at the very beginning of his [1965] essay, and which go right to the heart of his conception of explanation. The first was that all scientific explanations may be regarded as answers to why-questions (334). The second was that requests for explanations whose explanandum term is a nondescriptive singular referring device such as a noun make sense only when reconstrued in terms of why-questions (334). The third claim was that every adequate response to an explanation-seeking why-question should, in principle, be able to serve as an adequate response to an epistemic why-question (335). All these claims are connected. I begin with the first two.

The first claim is, of course, a fairly weak one, because it suggests only that we can use the why-question format, not that we must. In making this claim, Hempel was clearly influenced by considerations similar to ours, in that a given explanandum event will usually be multifaceted, and one needs to specify which aspect one needs to explain. Here is Hempel's argument:

> Sometimes the subject matter of an explanation, or the explanandum, is indicated by a noun, as when we ask for an explanation of the aurora borealis. It is important to realize that this kind of phrasing has a clear meaning only in so far as it can be restated in terms of why-questions. Thus in the context of an explanation, the aurora borealis must be taken to be characterized by certain distinctive general features, each of them describable by a that-clause, for example: that it is normally found only in fairly high northern latitudes; that it occurs intermittently; that sunspot maxima with their eleven-year cycle are regularly accompanied by maxima in the frequency and brightness of aurora borealis displays; that an aurora shows characteristic spectral lines of rare atmospheric gases, and so on. And to ask for an explanation of the aurora borealis is to request an explanation of why auroral displays occur in the fashion indicated and *why* they have physical characteristics such as those indicated. Indeed, requests for an explanation of the aurora borealis, of the tides, of solar eclipses in general or of some solar eclipse in particular, or of a given influenza epidemic, and the like have a clear meaning only if it is understood what aspects of the phenomenon in question are to be explained; and in that case the explanatory problem can again be expressed in the form 'Why is it the case that p?' where the place of 'p' is occupied by an empirical statement specifying the explanandum. Questions of this type will be called *explanation-seeking why-questions*. (334)

It is evident, however, that one can meaningfully request explanations without resorting to the why-question format.

When John Snow discovered the principal cause of cholera in 1849, he wrote: 'While the presumed contamination of the water of the Broad Street pump with the evacuations of cholera patients affords an exact explanation *of the fearful outbreak of cholera in St. James's parish*, there is no other circumstance which offers any explanation at all, whatever hypothesis of the nature and cause of the malady be adopted." (Snow [1855], 54, my emphasis added)

A more recent example from molecular biology comes from Crick and Watson: "[Wilkins et al.] have shown that the X-ray patterns of both the crystalline and paracrystalline forms is the same for all sources of DNA ranging from viruses to mammals. . . . It seemed to us that the most likely explanation *of these observations* was that the structure was based upon features common to all nucleotides." (Crick and Watson [1954], 83, emphasis added)

Here we have terms "the fearful outbreak of cholera in St. James's parish," "the X-ray patterns of both the crystalline and paracrystalline forms of DNA" which associate properties with systems (in the first case at a particular time, in the second at all times) in the way suggested by our ontology, and the appropriate accompanying question in each case would be "What is the explanation of X in S?" There are many more examples. It is common, and I believe meaningful, to ask for an explanation of such things as the increase in volume of a gas maintained at constant pressure; of the high incidence of recidivism among first-time offenders; of the occurrence of paresis in an individual; of the high inflation rate in an economy; of an eclipse of the sun; and of an influenza epidemic in a population. Indeed, even some requests couched in terms of Hempel's forbidden format appear to be meaningful and legitimate.

It appears to be appropriate for an individual to have asked Galileo or Newton for an explanation of the tides, or a meteorologist for an explanation of the aurora borealis. In the first case, what is being requested is an explanation of the periodic movements of the oceans on earth; in the second an explanation of the appearance of bright displays in the atmosphere in the northern latitudes. In each of these cases, and in each of the previous examples, the explanation requested is usually explicitly, sometimes implicitly, of the occurrence or change of a property associated with a system, and this, rather than the particular linguistic representation, is the important feature. So ordinary usage will not decide between the why-question approach and the one suggested here.[26]

Moreover, a review of some well-known problems accompanying the propositional approach should make us extremely wary of adopting it without being aware of these problems. First, within causal explanations, a propositional representation of the effect (explanandum) will also require a propositional representation of the causes. (A mixed ontology is theoretically possible, but given that most effects are also causes of further phenomena, and vice versa, a symmetric treatment seems advisable.) This then makes the causal relation one holding between propositions, and, as Davidson's well-known adaptation of a

Fregean argument shows (Davidson [1967]), given referential transparency of causal contexts plus substitution *salva veritate* of logical equivalents, propositional causal relations would turn out to be truth functional, which is obviously false. Next, consider what happens when the propositional approach is embedded in a nomological-inferential treatment of causation, as Hempel's was. As Kim (1973) argued, it is extremely difficult to control propositional descriptions of events so that all and only the appropriate inferences are made. Let $(x)\ (Fx \rightarrow Gx)$ be any true law which subsumes the cause-proposition Fa and the effect-proposition Ga. Let Hb be any true proposition. Then Hb, $H(\rceil x[x = b \wedge Fa])$ are both propositions describing the same event, i.e., b is H. But then $(x)(Fx \rightarrow Gx)$ together with $H(\rceil x[x = b \wedge Fa])$ allows us to derive Ga, so Hb causes Ga, according to the subsumption account. This is clearly unacceptable.

Next, recall Kyburg's example of the hexed salt: "All samples of hexed salt stirred in warm water dissolve. This sample of hexed salt was stirred in warm water. Hence this sample of salt dissolved." This satisfies all the criteria of adequacy for a deductive-nomological explanation, yet it is seriously misleading. Again, excess content which is causally irrelevant needs to be excluded from a propositional description to avoid this problem. Similar difficulties lie at the root of some of Salmon's counterexamples to the inductive statistical model of explanation (Salmon [1971], 33–40) although in others all the information given in the explanans is causally irrelevant, as is the case when the spontaneous evolution of a process is accompanied by irrelevant intervention. (Salmon's example of administering Vitamin C to cold sufferers fits this case.)

Each of these cases hinges on the difficulty of keeping out causally irrelevant information from propositions. But the problems are not in fact peculiar to propositional representations of explanation, because similar difficulties infect nominalizations of sentences. Consider Dretske's (1973), (1979) use of emphasis to produce terms referring to event allomorphs. Although his examples involved a combination of relevant and irrelevant causal information, we can construct parallel examples which involve a mixture of different kinds of causes. Consider

(1) The Afghan guerrillas' *surprise attack* after sunrise (caused)(explains) the crumbling of the defenses.
(2) The Afghan guerrillas' surprise attack *after sunrise* (caused)(explains) the crumbling of the defenses.

Given conventional military wisdom, (1) seems clearly to be true, while (2) is false. Compared to an attack with advance warning, a surprise attack increases the chances of victory and is a contributing cause to it. Compared to an attack before sunrise, a postdawn attack lowers the chances of victory and is a counteracting cause of it. What is occurring here, as Dretske noted about his examples involving relevant and irrelevant factors, is that stress markers pick out different aspects of spatio-temporal event descriptions and that far from being a pragmatic feature of ordinary discourse, these aspects are genuine features of the world.[27]

It should by now be clear what the common problem is with all these cases. Mere truth of the explanans and explanandum sentences will not prevent a conflation of relevant and irrelevant factors, or of contributing and counteracting causes. Successful reference to multiaspectival events will also allow such conflations. The most direct way to avoid such problems is to select a linguistic form which directly mirrors the separate structure of causal influences. There may well be other means of doing this than the one I have adopted here, but it will, I think, do the trick.

Appendix
The Causal Failures of the Covering-Law Model

It is now, I think, widely recognized that the original covering-law accounts of explanation were seriously defective in their treatment of causal explanations. Without wishing to retell a story already told, it is worth running quickly through the principal counterexamples to that account to bring out the causal nature of each of the failures.

(a) *The Flagpole Example*. Problem: A flagpole of height h casts a shadow of length l. With knowledge of the length of the shadow, of the angle of elevation of the sun, and of elementary laws of geometry and physics, such as the (almost) rectilinear propagation of light, we can deduce the value of h. But stating l does not explain h, although the deduction is a good D-N explanation.

Solution: The problem is clearly due to the fact that the shadow's length does not cause the flagpole's height, whereas the converse is true (because changing the flagpole's height while keeping other factors such as the sun's elevation constant results in a change in the flagpole's shadow,[28] whereas the converse is false.) This example is a classic case of the failure of the regularity analysis to capture the asymmetry of causal relations.

(b) *The Barometer Example*. Problem: One can deduce (or infer with high probability) from the regularity that falling barometer readings are (almost) always followed by storms, together with the statement that the barometer reading dropped, that a storm occurred.[29] Yet this is no explanation of the storm's occurrence, however good a predictor it might be.

Solution: The problem this time is the inability of the regularity analysis to distinguish a relation between joint effects of a common cause from a genuine causal relation. Here the common cause is a drop in the atmospheric pressure, and the two effects are the drop in the barometer reading and the occurrence of the storm. The explanation has failed to cite the cause of the storm, as is evidenced by the fact that altering the barometer reading, perhaps by heating and cooling the instrument, has no effect on the occurrence or nonoccurrence of the storm.

(c) *The Hexed Salt Example*. Problem: A sample of table salt is dissolved in warm water. The 'explanation' offered is that it was a sample of hexed salt, and samples of hexed salt always dissolve in warm water. Once again, this counts as a legitimate explanation under the D-N account, a clearly wrong conclusion.

Solution: As well as citing the cause of the salt's dissolving, which is its immersion in warm water, a factor which is not a cause (its hexing) has been cited. (The hexing is not a cause because changes in the property 'is hexed', from presence to absence do not result in changes in the property 'dissolves'.) On a causal account of explanation, this makes the explanation false, because something which is not a contributing cause has been (implicitly) claimed as a cause when it is not. Yet everything included in the explanans of the D-N 'explanation' is true, including the regularity that hexed salt always dissolves in water. Thus, the answer to the question raised by Salmon ([1984] p. 92) "Why are irrelevancies harmless to arguments but fatal to explanations?" is "Causal irrelevancies destroy the truth of a causal explanation, whereas arguments, which are concerned only with truth and validity, and not causality, have these features preserved under dilution by noncausal truths in the premises."[30]

(d) *Laws of Coexistence*. It has often been claimed that so-called laws of coexistence are not suitable as the basis of a causal explanation. Indeed, in denying that all explanations were causal Hempel ([1965], 352) cites the oft-repeated example of being able to explain the period of a pendulum by reference to its length, but not conversely, and makes the claim that laws of coexistence cannot provide causal explanations (in terms of antecedent events). Curiously, Hempel briefly discusses and then dismisses the essence of the correct response to this example, which is that the causal influence of the length on the period and the absence of a converse influence for a pendulum with a rigid rod is grounded not in a mathematical law statement, but in a physical procedure. Consider a rigid pendulum, but one whose center of mass can be altered by adjusting a bob. If l is the distance between the fulcrum and the center of mass, then the period is given by $t = 2\pi\sqrt{l/g}$. In this case, by physically changing l by means of raising and lowering the bob, the period t will change. However, because the pendulum is rigid, changing the period by forced oscillations will not result in a change in the distance of the center of mass from the fulcrum. Thus it is correct to say that the length of the pendulum is a cause of its period, whereas the period is not a cause of its length.

Suppose, in contrast, that the pendulum was elastic, and had forced oscillations. Then, in this case, we should correctly be able to say that the period of oscillation explains why the pendulum has the length that it does (strictly, the increase in length over the neutral state of no oscillations), because changing the period changes the length of the pendulum but, in this case where the oscillations are forced from outside the system, the converse does not hold.

(e) *The Causal Potential Overdetermination Problem*. In an example of Scriven's, and cited in Hempel (1965), a bridge is demolished by a charge just before a bomb explodes immediately over the bridge. The bomb is sufficient to destroy the bridge, so that a universal generalization of the form $(x)(Fx \rightarrow Gx)$ is true, where $Fx =_{df} x$ has a bomb explode in the immediate vicinity; $Gx =_{df} x$ is destroyed. Furthermore, both Fa and Ga are true. But the explanation of the bridge's collapse is not given by citing this generalization and the fact Fa. The causal potential overdetermination case is in fact a subcase of the explanatory irrelevancy problem but unlike the case where an extra factor which is *always* causally ineffective is cited, as in the hexed salt case, here it is an accidental feature of the situation that a factor which would ordinarily be explanatory is, because it is causally ineffective in this case, explanatorily ineffective.[31]

In cases of actual overdetermination, the situation is opaque. We have no clear criteria for identifying the cause in those cases unless (and this is in fact more common than admitted) the overdetermined event is different because of the presence of two sufficient factors rather than one. So a death by simultaneous action of cyanide and strychine is a different kind of death ffrom one by either poison alone. In fact, I seriously doubt whether, in the ontic mode, there *are* any genuine cases of overdetermination. A factor which left no trace on the effect would have contributed nothing to that effect, and would violate the principle of causal relevance.

Notes

This essay originated with a suggestion by Philip Kitcher and Wesley Salmon that the exposition of aleatory explanations in my (1981a) and (1983) was too cryptic to fully reveal what its ramifications were and exactly where it differs from other approaches. I should like to thank them for providing the opportunity to write a fuller account, and for stimulating discussions during the NEH seminar. I have also benefited from comments on earlier drafts by Robert Almeder and David Papineau. Earlier versions were read at the Unversity of Minnesota and the London School of Economics.

1. See Gottlieb et al. (1981), Masur et al. (1981), and for an early survey, Gottlieb et al. (1983).

2. Here and occasionally elsewhere I use the definite article for convenience. As we shall see below, the indefinite article is greatly to be preferred, so that we escape the prejudice that there is a unique explanation for any given phenomenon.

3. Etymological note: the original meaning of 'research' is a search for something; it has as source

the French 'recherche.' The modern, much looser meaning would correspond to 'rechercher,' as in re-search.

4. Strawson (1985) p. 115, for example, writes "we also speak of one thing explaining, or being the explanation of, another thing, as if explaining was a relation between the things. And so it is. But it is not a natural relation in the sense in which we perhaps think of causality as a natural relation. . . . It does not hold between things in the natural world, things to which we can assign places and times in nature. It holds between facts or truths. The two levels of relationship are often and easily confused or conflated in philosophical thought." The remarks in section IV of Davidson (1967) also exemplify this position, which is widely held. One aim of the present paper is to argue that this position ought to be reconsidered. The almost exclusive emphasis on linguistic explanations characterizes such otherwise diverse accounts as Aristotle's (*Posterior Analytics*, Book I, ch. 13); Popper (1959), §12; Nagel (1961); Hempel (1965); Bromberger (1966); Friedman (1974); Railton (1978); Fetzer (1981), chs. 5, 6; Kitcher (1981); Niinuluoto (1981); Brody (1973); van Fraassen (1980), ch. 5; Achinstein (1983). The emphasis on linguistic carriers of explanations is particularly striking in the case of those who have noted the central role of causation in explanation, yet have retained a sentential structure for their analyses. For example, Brody (1973), pp. 23, 25, explicitly retains the deductive-nomological explanatory framework, even while supplementing it with causal and essential properties.

5. See Appendix for a list of these failures.

6. See, in particular, Kim (1973) for a convincing set of arguments on this point.

7. Salmon (1984) is the best presentation of a theory along these lines. A formal development of probabilistic causality is given in my (1986a).

8. Probably the most philosophically thorough of these, as well as one of the earliest, is Bhaskhar (1975).

9. I acknowledge here that there are other kinds of explanation than those which cite causes of the explained phenomenon. Achinstein (1983) p. 93 notes three: an explanation of what is occurring; an explanation of the significance of something; an explanation of the purpose of something. There are many more uses of the term "explanation" in English—we ask a miscreant for an explanation of his behavior (give reasons for his actions) and an engineer for an explanation of how a pump works (this is often close to a causal explanation but emphasizes mechanisms). The fact that the English language contains such a variegated set of uses for the term 'explanation' is one reason why it seems preferable to work from causes to causal explanations rather than from a general sense of explanation down to a subcase.

10. See Harper (1975), pp. 139–42.

11. Too great an emphasis on causal sufficiency obscures the role played by multiplicity. Multiple causation within a framework which insists that causes must be sufficient for their effects leads to overdetermination, with the consequent difficulty of identifying causes. Of course, sufficient causes may have multiple components, as they do in INUS conditions for example. However, necessary conditions are merely a special case of contributing causes (q.v.), and *sine qua non* accounts in general are unable to represent counteracting causes in the sense intended below. For additional defects in the *sine qua non* approach, see my (1981b), §1.

12. Crudely, contributing causes increase the chance of the effect, counteracting causes lower it. A fuller discussion of these two types of causations may be found in §4 below and in my (1983).

13. The plague is estimated to have killed almost one third of the population of Europe during the Black Death of the fourteenth century. One wonders how much a single vial of tetracycline would have fetched at auction then, had it been available!

14. This is to be compared with Hempel's (1965), p. 334 "Why is it the case that p?" where p is a propositional entity, and Salmon's (1984), p. 34 "Why is it that x, which is an A, is also a B?" where x is an individual, and A and B are properties. I emphasize here, however, that linguistic explanations are not to be necessarily construed as answers to questions. They stand as entities in their own right.

15. This may illustrate one difference between explanation and understanding, for although it is only the contributing causes which explain the outcome, a specification of the counteracting causes is necessary in addition for a full understanding of how the phenomenon came about.

16. For a treatment of some of these factors, see Kibble (1966), pp. 151–54.

17. As, for example, does Quine (1970), p. 30. In Quine (1985) this is reiterated, with some reservations (p. 167).

18. The structure of events that I have used is essentially that which Jaegwon Kim has employed and argued for in a number of subtle and interesting papers (1971), (1973), (1976). I refer the reader to those articles for a detailed exposition of Kim's views. The arguments which led me to adopt this account are rather different from those used by Kim, which emphasize the logical structure of events.

19. These include the accounts given in Hempel (1965) (1968), Salmon (1984), Fetzer (1981), Railton (1978). For Hempel, the probability is a logical probability, which gives the degree of inductive support afforded to the explanandum sentence on the basis of the explanans. In Railton's D-N-P model of explanation, the probability value of the explanandum event's occurrence appears explicitly in both the probabilistic laws occurring in the explanans and in the statement of the probability of the explanandum fact (1978, p. 218). In Fetzer's causal relevance model, the strength of the propensity value occurring in the probabilistic conditional is an essential feature of the explanation. Salmon, I think, has come very close to giving up the probability requirement (1984, p. 266), but not completely because he asserts "we must give serious consideration to the idea that a probabilistic cause need not bear the relation of positive statistical relevance to its effect. . . . The answer . . . lies in the transmission of probabilistic causal influence." (p. 202) "The basic causal mechanism, in my opinion, is a causal process that carries with it probability distributions for various types of interaction." (p. 203) For a more detailed discussion of this point, see Humphreys (1986b).

20. This claim relies on interpreting a standard solution to the problem of the single case in a particular way, viz: A probability attribution $P(A/B) = r$ is *true* if and only if there is no further factor C such that $P(A/BC) \neq r$. Discussions of the single case issue tend not to talk in terms of truth, but of appropriate or correct reference classes or sequences. In fact, when discussing the problem of ambiguity (e.g., Hempel [1968], p. 117), Hempel claims that two incompatible relative frequency statements can both be true. In the sense that the relative frequencies $P(A/B) = r$ and $P(A/B') = r'$ are the frequencies relative to some reference class, this position is correct. However, because we are concerned with the explanandum event itself, and not a representation of it in a class, the appropriate probability is that of the single case, not of the type within a class. One also cannot preserve the ambiguity of probability values by claiming that applications of relative frequencies to single cases are relative to the explanandum sentence which describes the explanandum phenomenon, because then the two different probabilities would not be applied to the same object.

21. I myself doubt whether there are many genuine cases of pure probability distributions. This fact is disguised by the common use of uninterpreted parameters in representations of probability distributions, whereas even in cases such as the binomial distribution for coin tossing, the parameter p is a function of the center of gravity of the coin, and in the exponential distribution for radioactive decay, the parameter λ is a function of the atomic number of the atom. These factors are, it is true, usually structural aspects of the systems, but that does not necessarily rule them out as contributing factors. For more on this matter, see my (1986c).

22. I call a maximal specificity condition any condition which requires that all probabilistically relevant factors must be cited in an objective, nonepistemically relativized explanation.

23. I believe that this kind of causal approach also captures rather better than do traditional accounts how we approach closer to the whole truth. Many accounts of Carnapian verisimilitude use a counting measure on the degree of correspondence between correct state descriptions and proffered state descriptions. That can be replaced by a similar counting measure on $\Phi \cup \Psi$. One can make this more precise, and include a measure of the relative contributions of the causal factors to Y, by using such concepts as explained variance, but I shall not pursue that here.

24. I was myself unconsciously trapped by this in my first paper (1981a) where I unthinkingly used the mixed form of 'A because Φ, despite Ψ', which requires A and Φ to be propositional, yet Ψ to refer to events. I hence slurred over the distinctions by using 'despite the fact that' and the alternative 'even though' for counteracting causes, thus managing to stay within the propositional form. I have not discussed here the variant of the standard form 'Y in contrast to Z because X', which is used by van Fraassen (1980) and other pragmatically oriented writers. Much of what is said in this paper carries over with obvious modifications, although the issue of whether all explanations are comparative in form is not something I can cover here.

25. I use 'sentence' and 'proposition' as stylistic variants of each other here. No ontological distinction is intended.

26. As one might have expected. An earlier debate about linguistic evidence for and against fact-like entities as effects proved inconclusive. See Vendler (1962) and the accompanying papers by Bromberger and Dray. For the arguments that these debates are inconclusive, see Shorter (1965), especially p. 155.

27. The role played by emphasis in posing why-questions, as outlined by van Fraassen (1980), ch. 5 §4, poses different problems, in particular the generation of contrast classes and the related issue of whether questions are implicitly contrastive in form. Although these are important issues, I do not propose to deal with them here. (See note 24 above.)

28. Except for singularities at 0 and $\pi/2$ angles of elevation.

29. It is not evident to me that this regularity is lawlike, for the subjunctive conditional "Were that barometer reading to fall, a storm would occur" requires special constraints on the worlds in which the antecedent is true to preclude, among other things, human intervention from producing an artificial drop in the needle reading. Indeed, because this possibility is often present in these cases of causally spurious associations of common causes, many such regularities will fail the lawlikeness condition.

30. This answer is essentially that given by Salmon. Even though he phrases his answer in terms of statistical-relevance rather than causal relevance (1984, p. 96), it is clear from the causal apparatus employed later in the book that it is causal relevance that is meant.

31. Similar examples have been used by Achinstein (1983, p. 168) to argue that although it is often possible to determine *a priori* whether the formal requirements for a model of explanation have been met (as one can in Scriven's example) one also needs to have *a posteriori* knowledge beyond knowing the truth of the explanans – in Scriven's case we would need to know that no other cause of the bridge's collapse except the explosion of the bomb was present. Indeed, all Achinstein's examples against various models (168–70, 177–78, 180) are of the potential overdetermination type, and the knowledge required to avoid the problem is the knowledge of what the actual causes of the explanandum were. Thus because aleatory explanations require citation of only causal factors, they are not subject to this objection. Nevertheless, Achinstein would rule out aleatory explanations on the grounds that they violate what he calls the "no explanation by singular sentence" (NES) condition. This condition (p. 159) asserts that "no singular sentence in the explanans (no sentence describing *particular* events) and no conjunction of such sentences, can entail the explanandum." The three reasons he cites for imposing this condition are (a) to ban self explanation (b) to require that laws play an essential role in explanations (c) to remove explanatory connectives from the explanans. The first two of these conditions are satisfied by aleatory explanations. No empirical phenomenon is self caused. Our requirement of unconditionalness entails that causal relations ground laws. Regarding the third, no explicit mention of "causes" or "explains" appears in the explanans of an aleatory explanation. However, because Achinstein views the task of an explanatory model to analyze (away) terms such as 'causes' and 'explains', their appearance, implicitly or explicitly, in a model of explanation violates the constraints on such a task. I see no reason to impose the NES condition on aleatory explanations. As previously stated, our task is not to analyze the term 'causation', but to show how causal knowledge can be cumulatively used to provide explanatory knowledge.

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