

Cosmology II - Causation
[Revised version¹]

Causal Explanation

Explanations of the existence of something in terms of its form and the matter of which it is composed which we were considering in the last lecture seek to answer the question why things are as they are by, as it were, dissecting them and examining their internal structure. They do not attempt to answer the question why things of this kind should have come into existence, why they should cease to exist when they do cease to exist or why their accidental characteristics, properties and relations with other things should change during the course of their existence in the way they do. In other words formal and material explanations are *static*, concerned with the state of affairs which exists at a particular moment of time. Efficient or causal explanations by contrast are concerned with the explanation of change, with the *dynamic* aspects of things rather than with their static aspects, with why and how they come to exist or cease to exist and why and how their properties, characteristics and relations with other things change in the course of their existence in the way they do.

The distinction is not, however, quite as clean as this formulation would suggest since efficient causal explanations are also involved in giving an answer to how and why a static structure holds together in the way it does. Furthermore an account of the causal interdependence of the parts which constitute the matter of a thing on which its continued existence depends is an important part of the form of a thing in Aristotle's sense and, hence, an important part of what he would call a formal explanation or cause of it. It is, of course, possible to give an account of the matter of which a thing is composed and of the form in which the matter is arranged which mentions only the geographical or anatomical distribution of the parts constituting the matter without discussing their functional or causal relationship. There is a sense however, in which a substantial analysis of this kind would be purely *descriptive* rather than *explanatory*, since it answers the question *how* things are arranged, without answering such questions, as *why* they are arranged as they are, and *what effect* having that internal structure has on the properties of the whole. Furthermore, when the sub-microscopic levels of material analysis are reached, a purely descriptive analysis is no longer possible, since the units of analysis, such as atoms and sub-atomic particles, are too small to be observed, not merely by the most powerful microscope currently available, but by any microscope that might conceivably be constructed in the future. Consequently, our only grounds for believing in the existence of these unobservable sub-microscopic entities must necessarily be that their postulation is required in order to explain, in a causal sense of 'explain', effects which we can and do observe. As Hume (1739) pointed out long ago, any inference that we make to the existence of something that we have not and cannot observe, whether because it is in principle unobservable, as in the case of atoms and sub-atomic particles, or because it no longer exists to be observed, as in the case of matters of historical fact, necessarily involves either an inference from an observed cause to its unobserved effects or more commonly from an observed effect back to its unobserved cause.

Hume's account of the causal relation - what is still valid

Any philosophical discussion of the causal relation and its explanatory function must inevitably take Hume's discussion of the problem as its starting point. Hume's view of the matter is in many respects grossly defective. But there is one respect, at least, in which in my view, he is entirely right and that is in the central role which he gives to the causal relationship in all our reasoning about what he calls 'matters of fact'. This view of the crucial importance of the causal relationship is reiterated by Kant (1781/1787) when he argues that cause is an *a priori* concept or logical category which is indispensable to our understanding of any change or succession over time whereby something begins to exist, ceases to exist or undergoes a change in its properties. This view contrasts with that of many recent philosophers of science who have maintained that the causal relationship is a common sense concept which has no place in the laws and theories of modern physics. It is certainly true that the mathematical equations of theoretical physics do not employ any convention to distinguish cause or independent variables from effect or dependent variables. Nevertheless,

¹ Editor: The revisions are indicated by strikethroughs for the old text and square brackets for the new text. All the footnotes are new. The date of the revisions is unknown, but it must have been before 21 December 1991.

such a distinction, in my view, must always be tacitly introduced whenever the theoretical formulae are given an interpretation in terms of the realities of experimental observation.²

In addition to his recognition of the supreme importance of the causal relation in all our reasoning about matters of empirical fact, there are a number of other features of Hume's account which have stood the test of time and are still valid, alongside other aspects of his account which are either obscure or patently false.

Causation for Hume is a relation between one thing or set of things, the cause or causes and another thing or set of things, the effect or effects. But it is not a relation between concepts or 'ideas' as Hume calls them; it is a relationship that holds between matters of fact, between things which actually exist or occur in the world independently of our conception of them. The relation between cause and effect, moreover, is in some sense a necessary relationship, in that given the cause or causes, the effect or effects, in some sense, necessarily follow. However, a proposition of the form 'A caused B on a particular occasion' is not and logically cannot be a necessary truth, since a. Any such proposition is always contingent in that its denial involves no contradiction. Moreover, the same is true of universal propositions of the form 'things of type A always cause effects of type B'. [The reason for this is that it asserts the existence or occurrence of two spatio-temporally located states or events, and, as we saw in [the first lecture](#), such existential claims, unlike those of mathematics, are never simply a matter of linguistic or symbolic convention.³]

Finally, although he did not appreciate its significance for the solution of the problem of the necessary connection between cause and effect, Hume must also be credited with the recognition that particular causal judgements of the form 'A caused B on a particular occasion' entail some kind of universal proposition of the form, 'the occurrence of a thing of type A is invariably accompanied by the occurrence of things of type B.'

What is obscure

There are two important things which remain obscure in Hume's account of the causal relation. The first concerns the nature of the things between which the causal relation is supposed to hold. Hume sometimes speaks of causes and effects as 'objects', by which he means something like material substances in Aristotle's sense of term 'substance' which we were discussing in the previous lectures, and sometimes as events or occurrences. His failure to distinguish between these two existential categories and their respective roles in the causal relationship comes out in his contention that cause and effect are necessarily contiguous in both space and time. In fact the notion of the spatial contiguity of cause and effect only really make sense if cause and effect are construed as objects or material substances which come into physical contact with one another when a cause gives rise to or produces an effect. Events, considered apart from the substances involved in them, are not sufficiently firmly located in space for the notion of spatial contiguity to apply to them. Similarly, the notion of temporal contiguity which makes sense when applied to events has no application to objects or material substances considered apart from the events whereby they come into existence or cease to exist.

The second obscurity in Hume's account relates to the nature of the necessary connection that holds between a cause and its effect. Hume, it is true, attempts to account for our *belief* that effects necessarily follow from causes in terms of the psychological strength of our expectation that B will follow after having observed A, due to the repeated constant conjunction of the two things in our experience. But it is difficult to believe that even Hume himself was satisfied with this as an account of what it *means* to say that, given A, B necessarily and inevitably had to follow. Certainly no subsequent writer on the topic has found this part of Hume's account convincing, except as a psychological account of the origin of our causal beliefs, particularly those to which the fallacy of *post hoc propter hoc* applies.

² Ohm's Law is a case in point. There is nothing in the formula $R = E/I$ to indicate that potential difference (E) and resistance (R) are independent variables (causes) relative to current flow magnitude (I) as dependent variable (effect).

³ Universal causal law statements are a different matter. Since they make no claim to the spatio-temporally located existence of any object, state or event falling under them, they are frequently, if not invariably analytic and thus necessarily true. Again Ohm's Law is a case in point.

What is mistaken

In addition to these obscurities there are also certain respects in which Hume's account is demonstrably false. We have already seen in discussing Hume's thesis about the spatial and temporal contiguity of cause and effect, that he fails to draw the distinction between causes [in the sense of *causal agents*,] as objects or substances which act on other objects or substances (*effects*) [(the *causal patients*),] and causes and effects as events whereby one object acts on and thereby produces an effect or change in another ~~and that it~~. It] is to the relation between the objects or substances that the principle of spatial contiguity applies. It is to the relation between events, that the principle of temporal contiguity applies. But, even if we reformulate Hume's view so as to take account of this distinction, the thesis cannot be sustained[without considerable qualification].

In the spatial contiguity case there are plenty of examples where one substance or object acts on another without coming into a direct mechanical contact with it, as in the case of gravitation or magnetic attraction. Similarly, in the case of temporal contiguity there are many examples of events which can quite properly be said to be the cause of other events from which they are separated by long intervals of time. It is true that in such cases we usually expect to find some process such as the burning of a fuse which fills the temporal gap between the cause event and its effect ~~and we~~. We] may, if we wish, insist that it is the temporally contiguous event the burning of the fuse reaching the explosive, which is the *real* cause of the effect, ~~the explosion~~ [(the explosion)]; but that is not how we ordinarily talk, and there is no [particular] reason why we should do so, apart from the ~~desire to maintain the theory why we should be compelled to do so~~ [need we sometimes have to distinguish the event which actually *triggers* the effect from its other causes which are no less 'real' because they are more remote].

Hume's contention that causes must always precede their effects likewise only makes sense if causes and effects are understood as referring to events. It only makes sense to talk of objects or substances preceding other substances or objects in time in so far as the event of the coming into existence of the one precedes the event of the coming into existence of the other, in so far as the event of the one's acting on the other precedes the change in the other which is produced thereby. ~~There is however another possibility which needs to be considered in this connection, namely, that causes and effects are neither substances nor events, but states, as in the case of the interacting forces that maintain a state of balance or equilibrium. Here again it is only to events such as the coming into existence or subsequent disturbance of a state of equilibrium that the notion of the temporal precedence of cause and effect applies. As far as the state itself is concerned the causes or 'forces' which serve to maintain it, must coincide with it, but we need not in any intelligible sense precede it. Causal states of this kind often exist long before the state to which they contribute comes into existence; but they can equally well persist, not only through the period of its existence, but long after it has ceased to be. [But not all causal relations are relations between events. Some causal relations, such as that which holds between a state of balance or equilibrium and the forces which maintain it, are relations between states of affairs. In such cases the set of causes on whose existence the existence of a state of equilibrium depends does not precede the effect. It coincides with it. Individual components of the set may exist prior to the emergence of the state of equilibrium. Others may persist after the equilibrium has been disrupted. But in contrast to the case where the effect is an event, in the absence of the effect the persisting forces are not describable as its causes.]~~

But even if we restrict our attention to causal relations between events, there are many causal events which do not so much precede as coincide with their effects. For example, the event constituted by the heating of an explosive mixture to the point of ignition does not so much precede as coincide with its effect, the beginning of the explosion. It is true that where there is a measurable temporal gap between a cause event and an effect event, the cause event is invariably taken to be the one which is earlier in time; ~~but there are cases, so I understand, in the field of physics and electronics which constitute exceptions even to this principle. I should hasten to add, however, that the phenomenon known in psychology as 'retro active inhibition' does not need to be understood in terms of this kind of 'backwards causation'. [It would appear, moreover, that on closer inspection all cases where a later event is described as the cause of an earlier one turn out not to be genuine exceptions to the principle that causes either coincide with or precede their effects. A case in point is the phenomenon which is known to psychologists as 'retro-active inhibition.'~~

Properly understood, this is not a kind of ‘backwards causation.’ What is inhibited in this phenomenon is not the preceding event, but the persisting ‘trace’ or effect left by it in the nervous system.]

Another feature of Hume's account which is clearly mistaken is his [implicit] assumption that ~~because causal judgements, whether particular or universal, are always contingent and never necessarily true causal inferences are irrational in the sense that they cannot be validly deduced from premisses in accordance with the rules of logic.~~ [there is and can be a rational basis for causal prediction, that such predictions are simply a matter of habit. It is just that having repeatedly observed an event of the *A* type followed directly by an event of the *B* type, we come to expect an event of the *B* type whenever an event of the *A* type is observed. While expectations established in the way described by Hume undoubtedly play a vital role in the formation of our causal judgments. It is only when there is a discrepancy between expectation and the way things turn out in practice that we are led to think seriously about the causal mechanism that might account for this unusual phenomenon. Nor should [we] overlook the important role that is played by deductive reasoning in arriving at a considered judgment in such cases.] In fact, as Hume himself implicitly recognises when he includes the principle that ‘like causes produce like effects’ in the first of his two famous definitions of the causal relation (Hume, 1739, Book I, part III, Section XIV), any particular causal judgement is a valid deduction from a universal causal law of the form ‘whenever things of type *A* occur things of type *B* occur,’ together with a particular existential judgement to the effect that something of type *A* has occurred in the present case from which it follows that something of type *B* either has already occurred ~~also~~ [or will shortly do so.] ~~Hume's mistake here is to suppose that because neither the particular causal judgement nor the universal law are logically necessary truths, the particular causal judgement cannot follow from the universal law as a matter of logical necessity, as it clearly can.~~ [It may be that there are causal law statements which are nothing more than glorified empirical generalizations, principles that is to say which we accept on no firmer evidence than the constant conjunction of the two event types in our own personal past experience; but if so, such cases must be the exception rather than the rule. For the reasons given in §21 [principle 21] below, the standard case is one in which the causal statement is logically embedded in a theoretical framework of interlocking causal laws which serve to characterise the way in which different causal factors or variables interact to determine outcomes within a whole domain of scientific enquiry.]

~~It is Hume's failure to appreciate this point, I suggest, which leads him to put forward his psychological account of the origin of our causal beliefs in order to account for our inveterate propensity for making these supposedly invalid causal inferences in cases where we have repeatedly observed like causes giving rise to like effects.~~ [Not only is there an important role for deductive reasoning in teasing out the interaction between these different causal principles, deductive reasoning also has a vital role in moving from the universal principle to its predictions in the individual case. Hume is, of course, quite right to point that no argument from particular observations to a universal law statement can ever be a deductively valid argument.⁵ Where he is mistaken is in supposing

- (a) that inferences from observed constant conjunction to universal law statement are the only kind of inference involved in arriving at causal judgments, and
- (b) that we only make causal judgments in cases where we have repeatedly observed like causes giving rise to like effects.]

In fact, there are innumerable examples of causal judgements and inferences that we make without the slightest hesitation without ever having observed the actual concurrence of the cause and the effect. Consider the case of the judgement that the puncture was caused by a nail, stone or piece of glass penetrating the wall of the tyre. In this case what we repeatedly observe is not the penetration of the sharp object followed by the deflation, but the deflation of the tyre followed by the discovery of the object embedded in it. On Hume's account we should expect the formation in such circumstances of the judgement that the puncture caused the object to appear in the tyre wall, not the judgement that the object penetrating the tyre wall caused the puncture.

Another mistake, which is attributable not so much to Hume himself, as to a misguided application of his principle of the contingency of causal judgements by philosophers in recent years, is the notion that,

⁴ I have discussed this point in greater detail in my U. T. Place (1973) *The mental and the physical - a reply to Dr. Meynell. Heythrop Journal XIV*, 417-424.

⁵ The phrase ‘deductively valid’ is pleonastic. There is no such argument as an inductively valid argument.

if there is some kind of logical connection between the description of one event and the description of another event, these two events cannot be said to be causally connected. This argument has been used in order to deny that there is any kind of causal connection between someone's intention to perform a particular action and the performance of that action on the grounds that the description of something as an intention to perform a given action is logically parasitical upon the notion of performing an action of that kind. In such a case however, all that Hume's principle requires is that the *existence* or *occurrence* of an intention to perform an action should not entail the *existence* or *occurrence* of the performance itself and that the *existence* or *occurrence* of the action should not entail the *existence* or *occurrence* of an intention to perform it. Since it is not self contradictory to say that someone intended to do something which he did not in fact do or to say that he did something without intending to do it, it is clear that the logical connection between intending to do something and actually doing it, is not the kind of strict entailment which, on Hume's principle, would prevent an intention from being regarded as an efficient cause of the action in question.

Towards a better account

In attempting to replace Hume's account of the causal relation with something better, I would like to propose the following principles:

1. Something that stands as an *effect* in relation to some other thing or set of things which constitute its cause or causes is either an instantaneous event whereby some new state or process is brought into being or else an on-going state which is thereby maintained.
2. The existence of states and the occurrence of instantaneous events are both kinds of existence which are logically dependent upon the existence of some substance or other kind of independently existing thing in which or to which the change in question occurs (in the case of an event) or which is in the state in question and when the effect is a state. Hence the occurrence or existence of an effect entails the existence of a substance or other logically independent existent which we may refer to as the *object* or *patient* which undergoes the change or is in the state in question.
3. Something that stands as a *cause* or *causal factor* in relation to something else as effect is either some kind of occurrence which in turn may be either an on-going process or an instantaneous event or else an on-going state, where the difference between an on-going process and an on-going state lies in the fact that a process involves a continuous sequence of changes over time, whereas a state remains the same so long as it exists.
4. Since the occurrence of processes and events and the existence of states is logically dependent upon the existence of some substance or other logically independent existent in which or to which they occur or exist, the existence or occurrence of a cause or causal factor entails the existence of a substance or other logically independent existent which we may call the *causal agent* which is said to *act on* the object or patient whenever a cause or set of causal factors produces an effect. It should be noted in this connection that whereas, the cause and effect *qua* occurrences or states must always be separately and distinctly conceptualised events, processes or states, the causal agent and patient may be the same individual acting on itself, as in the case of *reflexive* action.
5. Whereas there is usually only one causal agent and one causal object or patient, causes and effects are *multiple*; in other words for any one particular effect there is always more than one distinguishable cause or causal factor and for any one particular set of causes or causal factor there may be more than one distinguishable effect.
6. To say that a particular set of causes or causal factors gave rise to a particular effect on a particular occasion entails that the same set of causes, if reproduced exactly on another occasion, would give rise to the same kind of effect. Such a situation may be described by saying that the set of causal factors in question are jointly *sufficient* for the occurrence of an effect of the kind in question. Any circumstance that is present on one occasion when the effect occurs, but is not present on some or all of the other occasions when the effect occurs with this particular constellation of jointly sufficient conditions, is not a member of the set of jointly sufficient conditions and is therefore not a causal factor with respect to the effect in question.
7. To say that of something that it is one of a set of conditions jointly sufficient for the occurrence or existence of a given effect is to say that it is one of the causes of that effect; but to say that something

is a cause of an effect in this sense is not to say that it is a *causally necessary condition* for the occurrence of a given effect in the sense in which causally necessary contrasts with causally sufficient. To say that a causal factor is a necessary condition for the occurrence or existence of an effect is to say that an effect of the kind in question does not and cannot occur or exist, *unless* the causal condition in question occurs or is present. There are many instances of types of effect which regularly result from a number of different sets of conditions each of which is jointly sufficient for the occurrence of an effect of the kind in question, but which may contain no common factor of which it is possible to assert that it is a necessary condition of the occurrence or existence of the effect in question.

8. Where an effect is the continued existence of an ongoing state, e.g. a state of equilibrium, all its causes must also be ongoing states rather than occurrences.
9. Where an effect is an event, i.e. the initiation of a new state or process all the causal factors present at the moment of initiation, with one exception, will be ongoing states which will have existed for a longer or shorter period of time prior to the occurrence of the effect and in many cases will persist after the event. There must however, always be one causal factor which is a[n] event whose occurrence completes the set of conditions sufficient for the occurrence of the effect in question. We may call this event the *triggering event*.
10. When we speak of something as *the* cause of an event as opposed to *a* cause of it, we are sometimes merely picking out one factor from a complex set of sufficient conditions which is of particular interest to us, because it differentiates an instance when an important event occurred from otherwise similar cases where the event in question failed to occur. In other cases the expression 'the cause' is used to designate the triggering event.
11. It is in the case of the triggering event that Hume's principle of temporal contiguity applies. Since the triggering event, as we have defined it, completes the set of causal conditions sufficient for the occurrence of the effect, the effect must occur *immediately* [after] the triggering event occurs. If it does not, it follows that the set of conditions is not yet complete, from which it follows that the supposed triggering event is not in fact what it has been taken to be, at least as far as the effect in question is concerned.
12. Where there is a time gap between an ostensible triggering event and the occurrence of the effect, the ostensible triggering event must be supposed either to bring into existence a state which requires the occurrence of another genuine triggering event with a high probability of occurring by chance within a short space of time in order to complete the set of sufficient conditions or, more commonly, to initiate an irreversible process whose completion constitutes the real triggering event in relation to the effect in question, e.g., the burning of a fuse.
13. The talk of *causal chains* in which one event causes another which in turn causes a third and so on applies primarily to a sequence of triggering events linked together by intervening states and processes in this way. The talk of causal chains usually ignores a whole range of concomitant causal conditions which contribute to the occurrence of the event at each stage of such a chain. The notion of a chain of causes and effects where each cause is both a necessary and a sufficient condition for the occurrence of its effect, and where each effect except the last stands as a causally necessary and sufficient condition for the next effect in the chain, may be described as the *determinist myth* analogous to the reductionist myth discussed in the previous lecture.
14. As we have seen (Section [or principle] 7 above) when we speak of conditions which are causally necessary for the existence or occurrence of something where this is contrasted with those conditions which are jointly sufficient for its occurrence or existence, we are talking in general terms about the causal conditions which apply in the case of effects of a given kind or type. However, there is also a sense in which any causal factor which contributes to the occurrence or existence of a particular effect on a particular occasion is causally necessary for the occurrence or existence of that effect on that occasion.
15. These two uses of 'causally necessary' are connected in that what is implied in the general case is that the kind of event or state which constitutes the effect does not occur, *unless* the causally necessary condition is present, whereas what is implied in the particular case is that the particular

- event which constitutes the effect would not have existed or occurred when it did, *if* the causal factor in question had *not* been present.
16. Thus both these senses of ‘causally necessary’ involve a ~~contrary-to-fact~~ [counterfactual] conditional proposition to the effect that if the causal factor in question had not occurred or been the case on the occasion or occasions in question, the effect would not have occurred or been the case.⁶
 17. ~~Contrary to fact~~ [Counterfactual] conditional propositions present a number of problems to logicians, but for our purposes we need only [to] note the problem presented by the fact that the state of affairs adverted to by such a proposition cannot only never be observed, it cannot exist and cannot therefore, be the referent of the proposition. Nevertheless, ~~contrary to fact~~, [counterfactual] conditional propositions are contingent propositions whose truth is somehow confirmed by observation.
 18. Since ~~contrary to fact~~ [counterfactual] conditional propositions do not refer to any state of affairs that exists or ever has or will exist, let alone anything that can be observed to exist, it follows that the truth of such a proposition can only be established by deducing it from some other proposition or set of propositions whose truth is more accessible to verification by observation. Now the only kind of proposition which will yield a counterfactual conditional as a deductive consequence is a universal proposition of the form of ‘Events or states of the effect type occur or are the case *if and only if* events or states of the cause type occur or are the case.’ This is the substantial basis for Hume’s thesis that particular causal judgements imply a[n] universal law to the effect that like causes produce like effects.
 19. The type of universal proposition that is needed in order to yield a ~~contra-to-fact~~ [counterfactual] conditional propositions as a valid deductive consequence, is the kind of universal proposition whose truth can never be conclusively determined by observation, since observation can only conclusively determine the truth of a universal proposition in the case where the number of members of the class to which it applies is logically finite, so that all possible members of the class can be inspected and the application of the principle demonstrated in each individual case. But as we have seen in a previous lecture the kind of universal proposition which extends over a class the number of whose members is finite is an accidental generalisation, like ‘everyone in this room is either a psychologist, a philosopher or a sociologist’; and as Mackie (1962) has pointed out, it is a feature of accidental generalisations which distinguish them from true universal propositions that counterfactual conditional propositions cannot be validly deduced from them. Thus given that it is true that everyone in this room is either a psychologist, a philosopher or a sociologist, we cannot validly deduce that if anyone else other than those actually present were to be in this room they would be either a psychologist, a philosopher or a sociologist. In other words, as Hume saw, there is no escape here from the problem of induction, considered as a means of establishing the truth of the universal law that is implied in any particular causal judgement, in that however many instances of its application we observe, we can never observe its application in all possible cases which is the range over which it must be taken to hold, if it is a genuine law rather than an accidental generalisation.
 20. The problem however[,] is even more complicated than this; the kind of universal law which is required in order to yield a counterfactual conditional as a valid deductive consequence must not only be open ended, it must also state conditions which are both *necessary and sufficient* for the occurrence of the effect in question. A proposition [of] the form ‘if an event or state of the cause

⁶ The earliest statement of this counterfactual theory of causal necessitation that I know of comes from Hume’s *Enquiry concerning the Human Understanding*, (Hume 1777). In the relevant passage Hume defines a cause as “An object, followed by another, and where all the objects similar to the first are followed by objects similar to the second. Or in other words *where if the first object had not been, the second had never existed.*” (Section VII, Part II, p. 76).

More recently this counterfactual theory of causal necessity has been developed by the late John Mackie in his ‘Counterfactuals and Causal Laws’ paper (Mackie 1962) and his book *The Cement of the Universe* (1974). It has also been defended by David Lewis (1973). My own commitment to the view goes back at least to 1956 when I wrote in a letter to the psychologist J. J. Gibson, commenting on some remarks he made on Michotte’s experiments on the perception of causation in [a draft of] his paper ‘Perception as a function of stimulation’ (Gibson 1959): “To say *A* causes *B* is to say ‘if *A* had not occurred, *B* would not have occurred.’ Whether or not this is so in a given case can only be determined by experiment. Causation as such gives rise to no characteristic stimulation, though certain kinds of causation, e.g. pushing, do. It is with them that Michotte is concerned.”

type exists or occurs, an event or state of the effect type will exist or occur', which merely states a set of sufficient conditions for the occurrence or existence of the type of effect in question, will not yield a counterfactual conditional as a valid consequence, since it tells in nothing about what happens in cases where these causal conditions are not present which is precisely the case which is adverted to by the counterfactual conditional. Only if it is strengthened to the form '*if and only if* an event or state of the cause type exists or occurs, will an event or state of the effect type exist or occur', will it yield a counterfactual conditional as a valid deductive consequence. It appears to follow from this that every particular causal judgement implies a universal causal law which states, not merely the causal conditions which are sufficient for the occurrence or existence of a state or event of the effect type in a situation of the kind in question, but the necessary and sufficient conditions for the occurrence of an effect of this type under any conditions whatsoever. This is a paradoxical conclusion in view of the fact to which we have already drawn attention that most causal judgements mention causal factors which are not only not necessary to the occurrence or existence of the effect, but are only one amongst a number of factors which are jointly sufficient for its occurrence or existence. This paradox can be made to seem less intractable when we consider that we can generate a universal proposition of the necessary and sufficient (*if and only if*) type which mentions the contribution of only one causal factor which is not by itself either necessary or sufficient for the occurrence or existence of the effect by inserting into the proposition a *ceteris paribus* clause which restricts its application to cases which are identical with the present case in all other relevant respects apart from the presence or absence of the causal factor in question. In other words, what is suggested is that particular causal judgements imply a universal proposition of the form 'Other things being equal, an event or state of the effect type will exist or occur, if and only if an event or state of the cause type exists or occurs.'

21. The fact that laws of nature as stated by scientists contain explicit or implicit *ceteris paribus* clauses of this kind has been noted by many philosophers of science, but it is usually regarded, particular by logicians, as a serious blemish which restricts the universality and precision of the principles which contain or imply it. The objection to the *ceteris paribus* clause is that if it is understood very literally, since every particular occasion is unique in some respect or other, the application of the universal proposition becomes restricted to the one particular case in question and thus loses its universality and hence any utility it might otherwise have had; but if it is interpreted more liberally as involving only those factors in the situation which are causally relevant to the existence or occurrence of the effect, although the universal proposition regains its universality and hence its utility, it only does so at the expense of vagueness and imprecision which can only be eliminated by specifying in detail all the other relevant causal factors which are jointly sufficient for the occurrence of an effect of the type in question in broadly similar circumstances. It follows from this that when everything is spelled out, a particular causal judgement entails, not merely one universal proposition to the effect that whenever a state or event of the cause type exists or occurs an event or state of the effect type exists or occurs, but a whole theoretical background of interlocking causal laws which apply in cases of this kind.
22. Moreover, whenever we try to formulate such a body of causal laws with any degree of precision, we find ourselves invariably and inescapably driven to formulate the relationships involved in quantitative rather than merely qualitative terms, so that we end up with a set of functional relationships between quantitatively measurable *independent variables* on the one hand and quantitatively measurable *dependent variables* on the other.
23. This, needless to say is the rationale behind the *experimental method* in which all possibly relevant independent variables are controlled and then systematically varied one by one in order to observe the resulting changes in the dependent variable or variables and which constitutes, in the last analysis, the only valid and reliable procedure for verifying and giving precision to causal judgements in any branch of scientific enquiry.
24. It is true that, however many times the experiment is repeated, the functional relationships yielded by a well controlled experiment are still contingent propositions, empirical hypotheses open to revision and rejection in the light of subsequent evidence. Nevertheless the truth of such functional

relationships as descriptions of the way things really are in the world can be asserted with much greater confidence than is possible in the case of a crude empirical generalisation made on the bases of superficial observation, however often it has been confirmed. The reason for this is that the different laws and principles, which emerge from an experimental programme in which the effect of all the different independent variables is systematically studied, form an interlocking body of scientific theory whose truth will become ever more difficult to question as it becomes logically tied into other related bodies of experimentally verified scientific theory and thus into the total scientific picture of the way things are in the universe.

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