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EXPLANATION IN ARISTOTLE, NEWTON, AND TOULMIN*

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Part I†

The claim that scientific explanation is deductive has been attacked on both systematic and historical grounds. This paper briefly defends the claim against the systematic attack. Essential to this defence is a distinction between perfect and imperfect explanation. This distinction is then used to illuminate the differences and similarities between Aristotelian (anthropomorphic) explanations of certain facts and those of classical mechanics. In particular, it is argued that when one attempts to fit classical mechanics into the Aristotelian framework the latter becomes structurally incoherent. It is suggested that this, together with the fact that classical mechanics embodied the first piece of perfect knowledge, accounts, in part at least, for the historical fact of the rapid demise of the Aristotelian patterns as the new science developed. On the basis of this discussion, the inadequacies of the attack on the deductive model on historical grounds by Toulmin come to be seen.

I

Science explains individual facts. Such explanation is deductive. (Sentences about) the facts to be explained are deduced from (sentences about) other individual facts ("initial conditions") and at least one statement of (scientific) law (Cf. [15]). Such explanation has as its ideal that the law be a process law (Cf. [3], [6]). Here are two assertions. I shall begin by briefly sketching their defence.

Scientific explanations are deductive because that is the only reasonable sense which can be given to "scientific explanation." That is how I propose to defend the first assertion. The defence of the second will be similar.

It is a fact that at least some of the things called explanations involve deductions of individual facts from initial conditions and laws. From this it does not follow that one can reasonably speak of scientific explanation[1] only in those cases where such deduction does in fact occur. It is necessary to indicate the feature of explanations by deduction from laws which justifies the philosopher's assertion that only explanations of this sort can reasonably be called scientific explanations.

Scientific explanations purport to show why the occurrence of certain events necessitates the occurrence of other events; why given the former, the latter must have occurred. A valid deductive argument is such that, if the premises are true,

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[1] There are, of course, other senses of 'explain': for example, one can explain to another the game of chess. But clearly this fact about 'explain' is not relevant to what we are about, in spite of what some presently maintain. Cf. Scriven [26] and, in response, Brodbeck [6].

then the conclusion cannot be false; given the premises, then the conclusion must be true. The point is that criteria for deductive validity are a matter of the (logical) forms of the sentences which appear in the argument. That is, the criteria are characteristics of the sentences themselves. They are not, for example, matters of "subjective taste"; they are not matters of how a person happens to react to the argument. (Cf. [33], Chs. 1 and 5, also [36].) Hence, an explanation by means of a valid deductive argument with (what we believe to be) true premises provides a reason, in terms of characteristics of the explanation (argument) itself and not in terms of how one might react to it, for one's saying that the event to be explained must have occurred. The form of the explanation (argument) is such as to guarantee that, given the premises, the event to be explained must have occurred. In terms of this feature of deductive explanations the philosopher explicates the sense in which a scientific explanation shows why, given certain events, other events must occur. The 'must' is that of logical deduction, of logical form. This explication provides the only reasonable sense which has ever been given to the notion of scientific explanation of individual facts.

It follows immediately that explanation and prediction have the same logical form. In predicting something as yet unknown, one deduces it from individual facts and laws which are already known. (One might note that "prediction" is not merely "forecasting"; one can also make predictions, in the relevant sense, about the past.) Because such prediction is a matter of deduction from premises, the failure of the prediction entails that at least one of the premises must be false.

Explanation being deductive, and symmetrical with prediction, it follows that if something can be explained then it could have been predicted, and if it can be predicted then it is thereby explained. But this is not strictly so, of course. There are two sorts of cases which purport to show this account of explanation to be inadequate as it stands. The first sort can be dismissed, the second cannot.

The first sort involves such examples as earthquakes. Here one can explain why an earthquake occurred, even though one could not have predicted it. This occurs by virtue of the complexity of the initial conditions which would have to be known in order to deduce from known laws the occurrence of an earthquake. They are simply too complex to be discovered prior to the earthquake. But, given that the earthquake has occurred, one can use the same laws to deduce (=predict, i.e. post-dict) that the extremely complex sufficient conditions for the earthquake must have been present. Thus, the earthquake is explained where it could not have been predicted.[2] Such cases as this can be dismissed, because they turn on the irrelevant fact that it is often difficult to find out what is the case.

The other sort of case which appears to confute the deductive model of scientific explanation involves such examples as weather forecasting. Here one has laws connecting, e.g., barometer readings and weather states. With barometer readings and the laws one can deduce (predict, forecast) the future state of the weather. Yet this in no way *explains* the weather.

[2] The field of history, especially human history, abounds with examples of this kind. These are made much of in the recent attacks on the deductive model. They can all be handled as I shall handle the earthquake case. Cf. Brodbeck [6].

Such examples as this establish that deduction can be but a necessary condition for something being reasonably labelled a scientific explanation. To find out what else is involved in an explanation being scientific, or, more accurately, in a scientific explanation being better or worse, one must turn to the ideal of scientific explanation, namely, process knowledge. The earliest instance of such knowledge was Newton's explanation of the motion of the objects of the solar system. Moreover, this remains the simplest example of such knowledge. For these reasons, it is excellent for illustrative purposes.

To possess process knowledge of a system, is to know three things about that system. *First*, one must know that the system is closed; i.e. that nothing outside the system affects what goes on inside the system.[3] This idea may be generalized to that of controlled boundary conditions. The solar system is closed. This is an inductive generalization, the truth of which is borne out by the success of the predictions of Newton and his successors. *Second*, one must know a complete set of relevant variables; i.e. that nothing else within the system affects the values of the variables of any member of this set. The masses, positions, and velocities form a complete set of relevant variables for the solar system. Or so the success of Newton's predictions makes it reasonable to believe. The values of these variables at any moment determine the state of the system at that moment. *Third*, one must know a process law for the system; i.e. one must know a formula such that, if one knows the state of the system at any one time (the values of all the relevant variables at any one time) then one can by means of the process formula compute the state of the system at any other time either earlier or later (the value of any relevant variable at any other time). Newton discovered a process law for the solar system.

Two features of process knowledge are significant. First, all the variables interact and the process law tells us how they interact. To say they interact means that the value of *any* variable in a later state of the system is a function (mathematical sense) of the values of *all* the variables in the earlier state of the system. If one has process knowledge then one knows all that there is to be known about the interaction of the variables. Second, the later state of the system, in all respects, depends on (is a function of) the earlier state, in all its respects, and on nothing else. In other words, the earlier state completely determines the later state.

By virtue of these features process knowledge is the ideal of scientific explanation. It is the ideal because it is a reasonable ideal. It is a reasonable ideal because in a very good sense process knowledge can be said to be perfect (Cf. [3], p. 100). If we have process knowledge of a system then one knows all that one could reasonably[4] want to know about that system in respect of the relevant variables.[5]

One may approach a system in respect of certain properties out of either idle

[3] The inside and outside here are spatial notions. Cf. Bergmann [3], p. 93 ff.

[4] 'Reasonably' rules out, for example, the demand that one overcome inductive uncertainty or the limits of measurement before claiming perfection. Such demands are impossible to fulfil and, for that reason, unreasonable. Cf. Bergmann [3], p. 98.

[5] But not in respect of other variables. With respect to masses, positions, and velocities of the planets we have (or at least approximate to) perfect knowledge. But the process knowledge provides us with no information about the colours of the planets. They are not among the relevant variables; they do not interact with the others.

curiosity or pragmatic interest.[6] Assume one has process knowledge of the system in respect of the properties in which one is interested. (Thus, the properties are members of the complete set of relevant variables.) The process law enables one to compute any future state of the system and any past state from the present state. This is the deterministic feature. In particular one will be able to compute the values of any of the variables in which one is interested for any future or past state of the system. Moreover, one can compute what would happen in any future state of the system if the value of any variable in the present state were to be changed, and what the past states of the system would have had to be in order for the value of the present variable to be other than what it is. This is the interaction feature. What more could one want to know as a matter of idle curiosity? Process knowledge gives one all one could reasonably want, out of idle curiosity, to know about a system in respect of certain properties. Moreover, if one has process knowledge then one can compute how to bring about by interference from the outside a variable's having a certain value, and one can compute the limits of such interference. What more could one want to know a matter of pragmatic interest? Process knowledge gives one all one could reasonably want, out of pragmatic interest, to know about a system in respect of certain properties.

If, then, we have process knowledge, our idle curiosity and pragmatic interest are completely satisfied. To call such knowledge perfect is, therefore, not unreasonable. Nor is it unreasonable that process knowledge has become, since Newton, the ideal of all scientific explanation of individual fact.

It is a necessary condition of a scientific explanation of individual fact that it be deductive. For an explanation to be the ideal of scientific explanation it is necessary and sufficient that the premises from which, together with initial conditions, one deduces the event to be explained, be those of process knowledge. We have just seen that these necessary and sufficient conditions for the ideal are not unreasonable.

But, of course, not all scientific explanations conform to the ideal. Process knowledge is perfect. Any piece of knowledge which falls short of this ideal can therefore be called "imperfect knowledge." Thus, Kepler's laws of planetary motion are pieces of imperfect knowledge. They are part of the perfect knowledge which Newton discovered about the planetary system. That is, they can be deduced from the process knowledge which we have of the solar system.

Kepler's laws are imperfect knowledge. That is not to condemn them. As far as they go, there is nothing wrong with them. The point is that they do not go far enough; that is, they do not go far enough in the sense that they do not tell us everything that one might want to know out of either idle curiosity or pragmatic interest. To call them imperfect is not to condemn them but merely to locate them relative to the ideal of all scientific explanation of individual fact: process knowledge.

From the process knowledge (if one has it) of an area, it is possible to deduce all the imperfect laws of the area. Thus, from Newton's law for the solar system one

[6] This way of putting it is Veblen's; see [31].

can deduce Kepler's laws. From the process knowledge of phenomenological thermodynamics, one can deduce the imperfect law that water when heated boils. But one can in fact improve on the imperfect knowledge. That is why it is imperfect. Imperfect laws typically have exceptions, holding only in certain conditions ("normal conditions"), and they typically ignore certain relevant factors. Thus, Kepler's law that planets move in elliptical orbits holds only approximately due to the perturbation effects of the other planets. From the process law one can deduce the necessary and sufficient conditions for a planetary orbit being an ellipse, and one can deduce the conditions under which the various deviations from the ellipse will occur. Again, the imperfect law that water when heated boils fails to cover such relevant features as the length of time it will take to boil, the temperature at which the water boils, the amount of heat required, the effects of pressure, and so on. From the process knowledge of thermodynamics one can deduce all these relevant features.

The imperfections of imperfect knowledge can thus all be accounted for if one can obtain perfect knowledge in the relevant area. The idea may be put this way: an explanation of an individual fact is scientific if, were one to have process knowledge in the area, then the explanation would be a part of that knowledge, that is, deducible from it.

The imperfections of imperfect knowledge do not alter the requirement of deduction. Imperfect laws can very well be the premises of scientific explanations in which a law plus initial conditions logically imply the event to be explained.[7]

Now return to the case of the use of a barometer to predict but not explain future states of the weather. The laws on which the predictions are based are pieces of imperfect knowledge. They are but a small part of what we in fact know about the systems in question. To be sure, we do not have process knowledge. What we know is not perfect, but it is in fact far closer to perfection than those laws connecting states of the barometer with states of the weather. It is this background of knowledge, far more satisfactory from the point of view of both idle curiosity and pragmatic interest (control and precautions), which provides what we call the explanation ("the real explanation") in question. Because it is far more satisfactory when measured against the ideal as contrasted to what is involved in just the forecast, we withhold what is in this context the essentially honorific title of explanation from the latter, restrict it to the former. This handles the crucial cases.[8]

Thus far all that has been discussed are scientific explanations of individual facts. These explanations are in terms of laws (plus initial conditions), ideally process laws. But science also explains laws. Laws are explained by theories (Cf. [3], pp. 31 ff.). Thus, Newton explained the process law for the solar system by means of his general theory of dynamics and gravitation.

Like 'explanation,' 'theory' has many uses. A reasonable sense must be given to it. A theory is a set of laws which are so inter-related deductively that they can be

[7] This point is well made in Brodbeck [6].

[8] This same point, neglected by many who write on the subject, e.g., Hempel and Oppenheim [15], who thereby unnecessarily lay themselves open to the criticisms of such a one as Scriven [26] or Toulmin [28], has recently been emphasized, and, indeed, pressed upon Hempel, by Clendinnen [10], pp. 99–101.

arranged into an axiomatic system; i.e. so related that from a small set of them (the axioms) the rest (the theorems) can all be logically deduced. To explain a law by means of a theory is to deduce the law from the axioms of the theory (Cf. [16]).

That this is *a* use of 'theory' and 'explain' is clear. We have the theory of mechanics which Newton first articulated, and which Newton used to explain the process law for the solar system, as well as for explaining a great many other laws, e.g. that of falling bodies. The fact of deduction in these theoretical explanations is, of course, crucial, for reasons that do not need repeating. It is the deductive connections which show why the law being explained *must* be as it is; that is, must be as it is, given the axioms from which it is deduced. It is the deductive connections which make it *reasonable* to speak of explanation when one says a theory explains a law.

However, deduction is but a necessary condition for one to speak of theories explaining. If it were sufficient, it would be easy to come up with explanations for laws. Axiomatizations are relatively easy. But most axiomatizations lack *scope*. Before an axiomatic system is to be counted as a theory capable of explaining the laws which are its theorems, the system must have a rather wide scope. Not very precisely (it is not worth making precise), this means that the laws in the theory should apply to a relatively wide range of systems, and that the laws should be significantly different from each other.

The feature of theories crucial to their having scope is the occurrence among their axioms of a *composition law* (Cf. [3], Chap. 3). What is involved in this notion can be best explained by turning to the example of Newton's mechanics. For this the composition law is the law of vector addition of forces or accelerations.[9]

One has a process law for two-body systems. Given a system containing two bodies, this law can be used to deduce any other state of the system given one state. This law tells us nothing about what will happen in three-body systems, or in four-body systems, or . . . or in *n*-body systems. Consider a three-body system. *Conceptually*, this can be "decomposed" into three two-body systems.[10] To each of these three two-body systems the already indicated process law can be applied. We can now apply the *factual* premiss of the composition law, and, from the laws for these three conceptually distinguished systems, we can deduce the process law for the three-body system.[11] The general idea of the composition law is that of a general premiss which will enable one to derive the process law for systems of any number of bodies given the process law for a two-body system.

It must be emphasized that such a law is just as much an empirical and inductive generalization as any other law. In particular, though it is independent of the process law for a simple system, it is as much a law as the latter.

[9] Subsequently in the paper, we shall discuss this further. Here my point is merely illustrative; later on I shall locate the law within the specific context of classical mechanics.

[10] The reason for emphasizing 'conceptually' appears in footnote 11.

[11] The point is that the system does not undergo three two-body processes, and that these, in some suitably vague sense of 'add', add up to a three-body process, or that the parts go through the processes they would go through if they were isolated. All the parts of the three-body system interact. That is why the two-body systems are only "conceptually distinguished." Cf. Russell [25], p. 484. The supposition that such a conceptual distinction is a real distinction is one of the roots of gestaltism in psychology. Cf. Madden [20]. Chapter One.

Clearly, the presence of such a law among the axioms of a theory will automatically confer upon the theory a wide scope. As a matter of fact, all known theories of importance contain such an axiom. It is this which gives to them the scope which is a necessary condition for an axiomatic system to be honored as a theory.

Toulmin has criticized the above account of scientific explanation in his book *Foresight and Understanding* [28]. Nor is the book merely critical. Toulmin offers an alternative account both of scientific explanations of individual facts, and of the role of theory in scientific explanation.

Toulmin notes the truth that if the deductive model of explanation is correct, then prediction and explanation are symmetrical. However, he argues, they are in fact not symmetrical, and therefore the deductive model is wrong.

His argument is this. Any satisfactory sense of *scientific* prediction takes for granted the idea of scientific explanation, rather than defining it. Scientists are concerned with forecasting techniques only incidentally. Centrally, science aims for understanding. Scientists search for a pattern which will make the course of nature not just predictable but intelligible ([28], pp. 34 ff., p. 45, and elsewhere).

With this, one who defends the deductive model need not, nor, if he is wise, will he disagree. Rather he will point to the ideal of scientific explanation of individual facts, namely, process knowledge, and he will point out that *mere* forecasting techniques fall far short of this ideal. It will follow that the scientist is, as Toulmin correctly asserts, interested in forecasting techniques only incidentally; and that the scientist is searching after explanations which approximate as closely as possible to the ideal. But it will not follow, as Toulmin incorrectly believes, that the deductive model, and therefore the symmetry between explanation and prediction (by means of process laws) must be given up.

What is it to find the course of (a portion of) nature *intelligible*? What is it to *understand* the sequence of events? The philosopher tries to answer these questions. He does not merely report the occasions which happen to elicit a "nod of understanding" from a listener. A person may hear a report, and respond with, "Ah, yes, now I understand," and the quizzical look disappears from his face. The philosopher cannot merely report the stimuli which happen to evoke such a response for the simple reason that in many cases the verbal stimulus does not *justify* the response. The philosopher asks the question, What sort of explanation would make it *reasonable* to say, "Now I understand"?

The answer to this question is by now clear. It is reasonable to say that one understands a system (understands it completely) only in case that one knows about the system everything that one might reasonably want to know about it, as a matter of either idle curiosity or pragmatic interest. One has such knowledge only if one has process knowledge. Hence, only in case that one has process knowledge of it can one reasonably say about a system that he completely understands what is going on in it over time. And one can more or less closely approximate this complete understanding as one's knowledge more or less closely approximates the ideal of process knowledge.

Toulmin argues that science has had at various times different ideals of intelligibility ([28], p. 58, pp. 109 ff.). First it had the Aristotelian ideal. Then it had the

Newtonian ideal—though Toulmin is careful to obscure the nature of this Newtonian ideal; he nowhere indicates the nature of Newton's success, that feature of it, namely, process, which so impressed (and rightly so) his successors such as Laplace.

It is true that Aristotle had a certain ideal of explanation. *It was not a scientific ideal. The scientific ideal is that of process. Nor was Aristotle's ideal even a reasonable one. For several reasons it falls far short of that complete understanding that process knowledge, and only process knowledge, can give.*

Aristotelian "science" was not science. It had an ideal of explanation different from that of science. Before Galileo there was no science, only Aristotelian "science." The explanations of events given by Aristotle and his successors are *different in kind* from explanations in terms of laws by scientists. Interest in the latter more or less began with Galileo (Cf. [31]). The ideal of explanation in terms of laws, namely, process knowledge, was first systematically defended by Descartes. The ideal was first achieved by Newton. So impressive was Newton's achievement, so clear was the perfection of the kind of knowledge he gave the world, that the Aristotelians were thereafter dead. Indeed, the Newtonian achievement rendered the Aristotelian patterns of explanation *logically incoherent. These are the points I hope to establish in this paper.*

Aristotelian "science" does, of course, embody pieces of imperfect knowledge in the sense defined above. To the extent that it embodies these, Aristotelian "science" embodies certain pieces of scientific knowledge. Toulmin, and others too, concentrate on these pieces of imperfect knowledge in an attempt to transform Aristotelian "science" into science. They ignore that behind these pieces of imperfect knowledge there is a *pattern* of explanation which is anything but scientific.

Indeed, one must say that not only does Aristotelian "science" have a different ideal of explanation than does science, but that the Aristotelian ideal is unreasonable, and, more importantly, is also such that it both logically and psychologically prevented progress from the imperfect knowledge already attained toward the reasonable ideal of scientific explanation.

I propose, therefore, to examine the Aristotelian ideal in order to distinguish it clearly and unequivocally from the scientific ideal.[12]

Every object has a Nature. A Nature is a systematic set of desires. What this set is depends on the kind of object one is talking about. These desires are for things as ends, and may be divided into two subclasses. There are those desires which an object has for its being something. Then its being that thing is pleasant. And there are those desires which an object has for its not being something; i.e. its aversions to being something. Then its being that thing is painful. And, let me repeat, these desires are for things as ends.

An event is analyzed into a Natured object having a certain property. Thus, the sentence 'This man is wise' represents an event. The phrase 'this man' refers to the Natured object; the phrase 'is wise' ascribes to this Natured object a property which

[12] My purposes are to present the patterns, not to interpret texts, and, therefore, while I believe my presentation to be faithful to the main outlines of the explanation patterns first systematized by Aristotle, I shall not bother except rarely to cite texts.

it has. The 'this' refers to a particular object: 'man' indicates the Nature of the object referred to, and to which the property is ascribed. The Nature is predicated of the object but is not present in the object; it is properties which are present in the object. (In saying that these are the relevant events, I am ignoring another kind of event, namely, that kind which Aristotelians refer to as "generation" and "corruption," events where one Nature is "lost," another "acquired."[13]) I shall say that events occur *in* Natured objects.

Events, in the sense indicated are to be explained. That is, explanations are to be given for (1) a Natured object continuing to have a property, and (2) a Natured object coming to have a property. To say the same thing differently, explanations are to be given for an event continuing and for an event coming to be. These explanations are in terms of (i) Natures, (ii) internal forces, and (iii) external forces.

I have already explained Natures, so I turn to the Aristotelian notion of force.

Aristotelian forces are volitional in form. Objects *strive* after ends or goals. The goal or end at which the striving is directed is a function of the Nature of the object whose striving it is. The strivings I shall say *belong to* that Natured object. This leaves open whether the strivings are events, that is, whether forces are in Natured objects in the way in which events are in Natured objects.

If a force is internal then the striving belongs to the Natured object in which occurs the event to be explained. If a force is external then the striving belongs to an object other than that in which occurs the event to be explained. If the force is internal to the object then the goal of the striving is a function of the Natural desires of the object; the object strives in such a way as to fulfil its Natural desires; it tries to be certain things and to not be certain other things according to its Nature. If the force is external to an object then it is internal to another object. Consider two objects S_1 and S_2. A force internal to S_2 acting as a force external to S_1 is such that (α) it has as its end the satisfaction of a desire of S_2; and (β) has as its end S_2 being in a certain (Natural) state; so that (γ) it is the desire of S_2 that S_1 be in a certain state (Natural, Unnatural, or accidental).

Aristotelian explanations must be given for events in the sense indicated, that is, for a Natured object continuing to have a property and for a Natured object coming to have a property. (An object ceasing to have a certain property is explained by indicating that it has come to have a contrary property.) An object continuing to have a certain property is explained by indicating that the object is in a certain *state*, either *Natural* or *Unnatural*. An object coming to have a certain property is explained by indicating that the object has undergone a certain *Aristotelian process*,[14] either *Natural* or *Unnatural*. (Those events which are *accidental* we temporarily ignore.)

An object is in a Natural state. In that case its Natural desires are being satisfied. It is what it desires to be and is not what it desires to not be. That is, it has the

[13] I ignore this case of substantial change because it is simply impossible to fit this into the Aristotelian patterns, as was seen by Leibniz and Spinoza; see Turnbull [30] and Bergmann [4].

[14] This is *not* a process in the sense defined by means of a process law.

properties it desires to have, and does not have those properties it desires to not have.[15]

An object is in an Unnatural state. In that case its Natural desires are not being satisfied. It is not what it desires to be and it is what it desires to not be.

An object has undergone a Natural Aristotelian process. In that case it has undergone a process which had as its goal the object being in a Natural state. At the beginning of the process, it was not what it desires to be; at the end of the process, it was (or was not) what it desires to (not) be; this Natural state which occurs at the end of the process was the goal of the process.

An object has undergone an Unnatural Aristotelian process. In that case it has undergone a process which has as its goal the object being in an Unnatural state. At first, it was not what it desires to be; at the end of the process it was in a certain Unnatural state (it was (was not) what it desires to not be (to be)) which was the goal of the process.

Explanations, as was indicated above, are in terms of Natures and of forces, either external or internal. These account for an object (a) continuing in a state, (a_1) a Natural state, (a_2) an Unnatural state; (b) undergoing an Aristotelian process, (b_1) a Natural process, (b_2) an Unnatural process.

Re. (a_1): An object continuing in a Natural state is explained by pointing out that (α) its Natural desires are being satisfied; and (β) all external forces striving to put it out of its Natural state are not sufficient to overcome internal forces striving to keep it in its Natural state.

Re. (b_1): An object undergoing a Natural process is explained by pointing out that (α) it is not in its Natural state; and (β) the internal forces, having the Natural state of the object as their end, are sufficient to overcome any external forces striving to keep the object out of its Natural state.

Since Natural Aristotelian processes are explained in this way, the meaning of the word 'sufficient' is such as to guarantee that the Natural state, which the internal forces are striving to bring about and for which they are sufficient, will in fact come about. In other words, if the internal forces are not sufficient to bring about that state, then the process is not a Natural process. *It is a necessary condition for an Aristotelian process to be a Natural process that the goal which the object is striving to bring about does in fact come about.* (I am, of course, here assuming that the objects in question neither judge nor deliberate about the goal in question. If either of these two occur, the former in the case of animals, the latter in the case of man alone, then things can go wrong as it were with the process besides the interference of external forces. But since we are here concerned with the objects with which mechanics deals the just asserted necessary condition for an Aristotelian process to be

[15] One can thus come to distinguish a Nature which is present in an object from the Nature which is predicated of the object. Call the former the "definitional," the latter the "dynamic" Nature. The definitional Nature consists of the set of properties which the object by virtue of its dynamic Nature desires to have present in it. The definitional Nature can be given a purely logical interpretation, belonging only to the context of description; the dynamic Nature cannot be so narrowly interpreted, since it is a causal notion, belonging to the context of explanation as well as to that of description. Cf. Bergmann [4]. What this amounts to saying is that the distinction between "present in" and "predicated of" is not a purely logical one, but is also causal. Cf. also Turnbull [29].

Natural holds; for the relevant objects neither judge nor deliberate, but simply strive.)

The explanation of Aristotelian *processes*, and in particular, Natural processes, is often stated in terms of Aristotelian causes. There are four Aristotelian causes. The "material cause" is the object which is undergoing the process. The "efficient cause" is the internal force (internal to the "material cause") which is appealed to in the explanation. The Natural state of the "material cause" which concludes the process, is the "final cause" of the process. Thus, the "final cause" is a state which exists at a time future to the operation of the "efficient cause." Moreover, it is a Natural state of the object (the "material cause") since, in this case, the process is a Natural one. And, of course, since the "efficient cause" is the striving to put the "material cause" in this Natural state, the "final cause" is the goal of the "efficient cause." Finally, there is the "formal cause": the "formal cause" is the *kind* of state the "material cause" will be in at the time when the "final cause" is achieved.

Now for two comments.

One. As a sub-kind of (b_1) we have the following: A process which has as its goal being something, where being this something is desired as a means to being something else desired for its own sake. There may of course be a whole series of such Aristotelian processes, each serving to bring about a means to something desired for its own sake. These instrumental processes form a series ordered by virtue of each member being a means for some "final cause" desired for its own sake, and by virtue of the whole series being initiated by an "efficient cause" or striving which has this "final cause" as its goal. Within this overall process it is clearly possible to distinguish a series of "efficient causes," a series of "formal causes," and a series of "final causes," each series being ordered by the means-end relation in which they stand to the overall process. Such a series of causes was said by the Medievals to be ordered *per se* (Cf. [8]). *A causal series ordered* per se *cannot regress to infinity.* For, it is self-contradictory to say people will a means and yet do not will an end; and a causal series ordered *per se* which regressed *ad infinitum* would be a regression of means and would contain no initiating volition which constituted the willing of the end.[16] Thus, the Medievals arrived at a god.[17] The argument is successful only if one accepts the Aristotelian pattern of explanation. There is (as we shall see) no reason to accept it, every reason to reject it.

Two. As another sub-kind of (b_1) we have the following: A process which has as its goal being something as a means to not being something else to which one has a Natural aversion, i.e., as a means to not being something else when one desires as an end to not be that something else.

[16] Patterson Brown [8] suggests that the Medievals thought an infinite regress of a series ordered *per se* was impossible because they were operating with what he refers to as the "legal notion" of causation: "I want to suggest that its salient feature . . . is the quasi-*legalistic* connotation of 'cause' which is employed. It is precisely the sense of a cause as *responsible* for its effect—as against its being merely a concomitant of its effect—which entails that *b*'s being moved by *c* renders the *true* statement '*b* moves *a*' unacceptable as the Aristotelian explanation of *a*'s motion" (p. 524; his italics). If I understand what he is driving at, then he is saying what I am saying.

[17] Cf. Aquinas, *Summa Theologiae*, I, 46, 2, reply to objection 7; and *Compendium Theologiae*, Part I, chapter 3. The relevant passages are translated in Aquinas [1], p. 77, and p. 158 respectively.

Return now to those Unnatural things requiring explanation.

Re. (a_2): An object continuing in an Unnatural state is explained by pointing out that (α) the object is not in its Natural state; (β) external forces are striving to keep it in its Unnatural state; and (γ) these external forces are sufficient to overcome the internal forces striving to return it to its Natural state.

In this case there are, of course, two objects, S_1 and S_2. S_1 is in an Unnatural state and S_2 is the source of the external force acting on S_1.

Re. (b_2): An object undergoing an Unnatural process is explained by pointing out that (α) the object is not in its Natural state; (β) the object is not in a certain Unnatural state; (γ) external forces are striving to put the object in that Unnatural state; and (δ) the external forces are sufficient to overcome the internal forces striving to return to its Natural state.

Here again we have two objects, S_1 and S_2. S_1 is undergoing the Unnatural process and S_2 is the source of the external forces acting on S_1. In a process of this kind, the "material cause" is the object undergoing the process, i.e., S_1. The "efficient cause" is the force external to S_1 and internal to S_2. The "final cause" is the state of S_1 desired by S_2 and which is the goal of the strivings of S_2, i.e. of the "efficient cause" of the process. And the "formal cause" is the *kind* of state that S_2 desires that S_1 be in.

Now for three comments.

One. External forces are internal to S_2. Their goal is S_1 being in a certain state (Natural, Unnatural, or accidental). But this goal will always be a means to some end, for the strivings of S_2 always have as their ultimate end S_2 being in a certain Natural state. Thus, in (a_2) the strivings of S_2 keep S_1 in a state which is a sufficient means to the end for which S_2 is striving. And in (b_2) S_1 is not yet in a state sufficient as a means to the end of S_2's strivings, but S_2's strivings have such a state as their goal or proximate end as it were.

Two. Operations of external forces are always in terms of *contact*. The object S_2 bringing about the change must come into contact with S_1 when it brings about in S_1 the event it desires. Although this is not entailed by the Aristotelian position, it is structurally almost unavoidable. Consider, first, the Natural coming to be of an event in S_2. The model is a VOLITION *belonging to* S_2 bringing about an event *in* S_2. *My* will brings about the rising of *my* arm. This model is to be extended to the external case. *Your* arm must be brought into a relation to *my* will as nearly similar as possible to the relation that *my* arm stands to *my* will. I raise your arm by *lifting it*, by reaching out and grasping it and then raising my arm: under normal circumstances the event comes to be in you of your arm going up. And I bring about this event for *my* reasons, not yours (though you may be indifferent). The whole anthropomorphic model brings into immediate operation the idea of a tool being used or an object being manipulated or worked upon. This very point finds its embodiment in the Aristotelian contrast of Nature and Art, but Art is merely a special case of the operation of external forces. More crucially for present purposes, however, is that the idea of external forces is wedded in the anthropomorphic model to that of a person using an instrument. Here is where contact comes in, for, clearly, the primary way of effecting changes in the world is by interfering by contact. Thus, contact becomes an essential feature of the operation of external forces. (So, since they were wedded to causation by contact, and only contact, the classical atomists of Aristotle's day were every bit as anthropomorphic as he. It is just that he emphasized one aspect of the basic model, they another.)

(I just said that the primary way of effecting changes is by contact. This is not wholly true. There is also manipulation by *word*. This is a still more primitive model for causation, and finds its embodiment in such practices as that of religious prayer and worship, either at the level where all objects are or are infused with communicating spirits, or at the more sublimated level of monotheism. It was Aristotle who destroyed this animism as any sort of intellectual force, though it did, of course, survive as a non-intellectual force, and was often in fact rationalized, to be sure unsuccessfully, along Aristotelian lines. Aristotle's achievement in systematizing and articulating the gropings of his predecessors into an organized doctrine of explanation which replaced and moved beyond a crude animism to a far more sophisticated anthropomorphism is of utmost importance in the intellectual history of man, and cannot but stand as a permanent monument to his supreme genius. It does not follow that the doctrine is true.)

Three. External forces, i.e. *transeunt* causes, always formed the stumbling block to the Aristotelians. The models of volition and the use of tools are clear enough as far as they go, so the logical difficulties involved were never strong enough to lead to a search for another idea of explanation. It was only when these basic models themselves were rendered structurally incoherent in the context of the developing mechanics at the time of Galileo, Descartes, and Newton that they were replaced by a new kind of explanation pattern. The logical difficulties arise when one considered the notion of an event in Aristotelian terms. An event occurs *in* a substance. Ontologically this amounts to the claim that only substances and their properties exist. (Speaking of events rather than simply properties emphasizes that Aristotelian substances have an essential explanatory role in the Aristotelian metaphysics-physics, not merely a logical or ontological role: properties are not merely in substances; their being in substances are events brought about by the activities, strivings *of* the substances.) It clearly leaves no room for *relations*. Yet transeunt causation is essentially relational. It involves *two* substances, and a *transaction* from the one (the agent, who exerts the external force) to the other (the patient, who is acted upon by the agent). This internal difficulty can be resolved while retaining the anthropomorphism only by eliminating transeunt causation, i.e. external forces, a point seen clearly only in the end by Spinoza and Leibniz, and unfortunately not at all by those at Oxford and elsewhere who now speak of actions and basic actions in the context of an attempt before our very eyes to revive the Aristotelian anthropomorphism one would have hoped science to have long since rendered obviously inadequate. As for Spinoza and Leibniz, they were willing to pay the price of no external forces, since they (unlike Oxford) accepted the emerging science, which (as we shall see below) rendered the Aristotelian patterns inadequate so far as explanations of the behavior of ordinary objects was concerned.[18]

[18] Cf. Bergmann [4] and Turnbull [30]. Weinberg [32], the essay "Relation," *passim*, and in particular pp. 76–77 elucidates these logical difficulties excellently. Cf. also [37].

An object's Nature is a systematic set of desires for things for their own sakes. But there are certain other things which an object may neither desire to be nor to not be. Such events are said to be *accidental*. For example, a piece of bronze having a certain shape would constitute an accidental event; for a piece of bronze is not by its Nature any particular shape.

Aristotelian explanations must be given for accidental events, that is, for a Natured object continuing to have an accidental property, and for a Natured object coming to have an accidental property. (An object ceasing to have an accidental property is explained by indicating that it has come to have a contrary property.) Explanations are in terms of accidental states and processes. They are required to account for (A) an object continuing in an accidental state; and (B) an object undergoing a process of accidental change. These explanations are in terms of (i) Natures; (ii) internal forces; (iii) external forces; and (iv) chance. Only (iv) requires further discussion; this will be given below.

Re. (A): An object continuing in an accidental state is explained by pointing out that there are no forces, either external or internal, striving to put the object in another state. (There is no change unless there are forces.) Thus, a lump of bronze will retain its shape in the absence of any forces; that is, the bronze retains its shape just in case changing its shape is not a means to some end which the lump of bronze Naturally desires (e.g. solidification), and that it is not a means to some end which some other object (e.g. a sculptor) desires.

Re. (B): An object undergoing a process of accidental change is explained in one of three mutually exclusive and jointly exhaustive ways.

(B_1) It may be explained by pointing to (α) an internal force which takes this change to be a means toward being (not being) something which it desires (has an aversion to) as an end; and which (β) is sufficient to overcome any external forces which might be striving to prevent this change. Thus, we have the oak undergoing accidental changes of height as it undergoes the process of maturing from acorn to full-grown tree.

(B_2) It may be explained by pointing to (α) an external force acting on the object, S_1, undergoing the process. This force, internal to S_2, is (β) a striving to have S_1 in the accidental state as a means to S_2 being in a state which S_2 Naturally desires as an end. Moreover, this force is (γ) sufficient to overcome any internal forces which might be striving to keep S_1 from being in the accidental state. Thus, we have the case of a man making a bronze knife. The accidents (shape) of the lump of bronze (S_1) change because the man (S_2) wishes the bronze to have the knife shape as a means to the end of cutting.[19]

(B_3) An object undergoing an Aristotelian process of accidental change may be explained by appeal to *chance*.[20] Suppose it is S_1 which changes accidentally. Suppose the following four things obtain. (α) S_1 is in a state or undergoing a process towards some state, for which the accidental change in question is neither a means nor an end. (β) S_2 is in a state or undergoing a process towards some state, for which

[19] Cutting is, of course, but a means to further ends, such as assimilating food.

[20] This usage of 'chance' is slightly broader than Aristotle's own. He restricts the notion to the case of humans. Yet the notion can be generalized, and this is all that I have done.

the accidental change in question is neither a means nor an end. (γ) S_2 comes into contact with S_1. (The model of knocking something over—accidentally!—as an extension of that of an instrument comes into play here.) (δ) S_1 changes accidentally in the way being explained. Then, the explanation by chance of the change in S_1 is constituted by pointing out that (α), (β), and (γ) obtain.[21] Note, first, that "chance" is not another force, or striving. Hence, one speaks of "blind chance." Note, second, that if explanations are to be in terms of forces, then, though forces are indeed present, it is nonetheless true that none of these forces has as its goal the accidental state which is the consequence of the process; that therefore none of the forces are *per se* relevant to the change being explained; and that therefore the process is in an obvious sense one that cannot be explained ("other than by chance").

Three examples will be useful, both for understanding what has just been said and also what follows.[22]

One. Consider the motion of the planets on the Aristotelian scheme. The *Natural state* of a planet is to move in circles at constant velocity. This shows that a Natural state need not be one of rest.

Two. Consider a stone. It is in its Natural state when it is as close to the centre of the universe as possible. Its weight is simply its striving to maintain this state. The bigger it is the harder it can strive. If it is not in its Natural state then, in the absence of external forces, it will undergo a Natural Aristotelian process of motion in a straight line toward the centre of the universe as it strives to get to its Natural state. Since its weight is its resistance to leaving its Natural state, and therefore simply its strivings to be in that state, the more an object weighs the harder it will strive to reach its Natural state. And so heavier objects will fall faster than lighter objects.[23] Since a stone has basically but one desire in its Nature, namely, to be as close to the centre of the universe as possible, it will move toward the state satisfying this desire in none but a direct manner. If it moves in an indirect manner, as in the case of projectiles, then there will have to be a force acting, which force can only be external, and which, moveover, will have to be constantly applied.[24]

Three. Consider a cart which is in motion, being pulled by a horse. The Natural state of the cart is one of rest, just as the stone. It is moving, and yet striving to return to a state of rest (it resists the horse). On the other hand, the external force of the horse is sufficient to overcome this striving, and so the cart moves, i.e. undergoes an Unnatural Aristotelian process. The horse is moved by its own strivings. It has a certain Natural end (e.g. food) and the means to this end is the movement of the cart to a certain place (at which point its master will feed it). So it exerts the force, internal to it, which, externally to the cart, moves the latter.

What, then, does one want to say about the explanations on the Aristotelian

[21] Cf. Ross [27]: "Chance is simply a name for the unforeseen meeting of two chains of rigorous causation" (p. 80).

[22] Kuhn [18] brings out well the anthropomorphism of Aristotle in the case of physical and astronomical explanations; see especially chapter 3.

[23] These points come out best when Aristotle is arguing for the motionless earth: see *De Caelo*, 297a9 ff., in Aristotle [2], p. 435 f.

[24] Cf. *Physica*, 266b27 ff., in Aristotle [2], p. 392.

patterns, in terms of Natures (desires), and forces (strivings, volitions), both internal and external to the object whose behavior is being explained?

The obvious and most crucial point, and, indeed, the condemning point, is that the explanations are anthropomorphic. Human attributes (desires, strivings) are attributed to what is nonhuman. More importantly, the explanations are teleological, in terms of final causes, and strivings after these; thus, even explanations of human activities are illegitimately anthropomorphic.

To be sure, Aristotelian explanations involve pieces of imperfect knowledge. And, to the extent that such knowledge is involved, Aristotelian explanations embody scientific explanations. However, to explain on the Aristotelian patterns requires that one appeal to more than a generality. Indeed, the generality is but an incidental aspect of the Aristotelian explanation. It is slighting of the generality which renders Aristotelian explanations inadequate, even in the case of explanations of human behavior.

Consider the case of the stone falling vertically. The piece of imperfect knowledge which is involved is the generality (G) "Unsupported heavy objects fall vertically." (G) is imperfect; it does not, for example, tell us how long an object will take to fall a given distance. The perfect knowledge of which (G) is a part was discovered by Newton building on the invaluable work of Galileo. However, even if (G) is not perfect, it can appear in a scientific explanation. Thus, the initial condition "This stone is heavy and unsupported" and (G) jointly explain why this stone is falling vertically. And this explanation, while not perfect, is scientific, and, as far as it goes, quite acceptable. However, in the Aristotelian explanations, this does not suffice. The crucial move is to the strivings of the stone. It is these which provide the explanation. (G) enters into the picture only by virtue of the fact that the stone strives in such a way as to make the generality (G) come out true. That is, *on the Aristotelian patterns the generalities explain nothing; rather, they are themselves to be explained in terms of the strivings of the objects involved: the objects striving after certain goals* (*what the goals are depends on the Nature = desires of the object*) *account for the general facts being as they are.* Or, in other words, *from the viewpoint of the Aristotelian patterns of explanation, scientific explanations merely provide the description of the behavior of the objects, but fail to provide an explanation* (i.e. Aristotelian explanation in terms of Natures and strivings).

In short, although Aristotelian explanations embody pieces of imperfect knowledge, the patterns of explanation are radically different from those of scientific explanations.

Though there is nothing in principle inconsistent in the suggestion that an Aristotelian explanation might involve a process law rather than imperfect laws, in point of fact all explanations ever offered by Aristotelians (before the Newtonian triumph) involved nothing better than imperfect knowledge. Thus, none of them ever provided complete understanding in the way that Newton provided us with a complete understanding of the solar system. *Logically and psychologically the Aristotelian patterns worked to prevent progress beyond the bits of imperfect knowledge they involved toward the goal of perfect understanding, i.e. toward process knowledge.*

There are several points in the Aristotelian explanations which provide logical bars with respect to progress toward the ideal of process knowledge.

In the first place, the Aristotelian patterns draw a distinction in kind between states and Aristotelian processes. Within the Newtonian process scheme, Aristotelian states amount more or less to states in which equilibrium conditions occur, and Aristotelian processes amount to states (series of states) of a non-equilibrium sort.[25] The Aristotelian distinction of kind between states and processes prevents one from seeing that the two may in fact be part of the same process, in the Newtonian (scientific) sense of the term. If one concentrates separately on the Aristotelian state and on the Aristotelian process, then all that one has are two pieces of imperfect knowledge. One can more closely approximate to the scientific ideal only by as it were putting these together. But within the Aristotelian framework one cannot put them together: in that context they are radically different in kind.

Furthermore, in many cases the search after Aristotelian explanations can simply set one off on the wrong track. This is not only by virtue of the patterns leading to the false attribution of desires, volitions, and purposes to inanimate objects. It is also by virtue of the requirement the Aristotelian patterns impose that every Aristotelian process have its termination in an Aristotelian state. Translated into the terms of a Newtonian process, this amounts to the suggestion that every system undergoing a Newtonian process comes finally to be in equilibrium.[26] There is nothing in the notion of a scientific process which requires this. Whether or not equilibrium will come about will depend in general on both the nature of the process law involved and on the initial conditions. The Aristotelian patterns prevent one from seeing this.

Again the Aristotelian patterns draw a radical distinction between internal and external forces (or, what amounts practically to the same, between Natural and Unnatural Aristotelian states and processes). In less explicitly anthropomorphic terms, the Aristotelian patterns impose upon one a radical distinction between causes and conditions. This prevents one from seeing that so far as being part of a scientific process, there is no such distinction: there are only relevant variables.

Finally, upon the Aristotelian patterns there are certain events which go unexplained, namely, those explained by chance. If one thinks in the Newtonian pattern, in terms of interacting variables and of laws governing this interaction, then chance events are as explainable as any others, and explainable in exactly the same way.

Besides these logical bars to progress (and one could mention more), the Aristotelian patterns also present a psychological bar. The anthropomorphism of these explanations finds its roots in, and appeals to, the infantile part of our psychological apparatus. We "understand" ourselves, and therefore we "understand" the objects whose behavior we are explaining because those objects *are* ourselves by virtue of the anthropomorphic projections. We fool ourselves that we have complete "understanding." The result is that we don't desire more by way of knowledge.

[25] The notion of an equilibrium law is explained in Bergmann [3], p. 102 f.

[26] One could speak of a "stable equilibrium" in case that the process was Natural, and an "unstable equilibrium" in case that the process was Unnatural.

The mechanism implicit in the anthropomorphism of the Aristotelian patterns prevents us from desiring the perfect knowledge found only in Newtonian process knowledge; it lets us rest content with pieces of imperfect knowledge.

Aristotelian "science" involves bits of imperfect knowledge. There are those, Toulmin among them, who wish to assimilate this "science" to science. To this end, they concentrate on the imperfect knowledge Aristotelian "science" provides. Simultaneously, they ignore the fact that beyond the bits of imperfect knowledge there is a *pattern* of explanation which is quite different from the pattern of scientific explanation. Not only is the latter superior to the former, but the former, both logically and psychologically, prevents progress toward the scientific ideal of process knowledge. This is ignored, and is crucial.

Toulmin argues that science has not one aim but many ([28], pp. 109 ff.). In a sense this is true. There are different approaches to different problems. Different variables are thought to be relevant in different areas. Interaction is thought to take place in different ways. In this sense science has not one aim but many. On the other hand, it has but one aim in the sense that there is but one (reasonable) ideal of scientific explanation, namely, process knowledge. Aristotelian "science" is not science because it has a different ideal or pattern of explanation. Before Galileo there was no science. Before Descartes the ideal of science was not even articulated. Before Newton the ideal was not even reasonably approximated. The astounding success of Newton killed Aristotelian "science." It was soon realized by such men as Laplace that the power of Newton lay in the achievement of process knowledge. The Aristotelian patterns soon died (in physics, among physicists).

One cannot point to Aristotelian "science" and argue that therefore science has many ideals of explanation. The former is not science; the ideals of explanation differ radically; the ideal of science is to be preferred (by rational people) to the ideal of Aristotelian "science." Yet it is to Aristotelian "science" that Toulmin appeals in his zeal to attack the deductive model of scientific explanation. That attack is, we saw, based largely on misunderstanding the model. It will pay to examine how he exploits the appeal to Aristotelian "science."

We might well begin by considering two examples used by Toulmin ([28], pp. 59 f.). The first is this. If a car travels normally down the street, one does not wonder. If it jerks along and backfires then one wonders. The second is this. If Jupiter continues to travel in its orbit then the astronomer is not surprised. If it were to fly off at a tangent then the astronomer would wonder.

Toulmin describes these cases as follows. Where there is no wonder on the part of the observer, the objects are behaving naturally (the use of 'natural' is his). Where there is wonder the objects are behaving unnaturally. In the case of natural behavior no explanation is demanded. In the case of unnatural behavior an explanation is demanded; that is the point of the wonder. I suggest that Toulmin is simply attempting to revive the Aristotelian distinction between explaining the behavior of an object when it is in a state and when it is undergoing an (Aristotelian) process; these are the two cases: no wonder on the part of the observer, and wonder on the part of the observer. (It is clear the two cases correspond to Natural states, on the one hand, and Unnatural processes and states, on the other, with no mention of Natural processes: we shall see below why Toulmin makes this omission.) But Toulmin's attempt to revive Aristotle fails.

What is crucial is how to account for the differing responses of the observer (wonder; no wonder). Toulmin suggests that only the Aristotelian patterns can provide this account. Let us see.

Consider the case of Jupiter. It is continuing in its orbit. The astronomer expresses no wonder at this. Toulmin asserts that this is because the planet is doing "what is natural." The absence of wonder is equally well accounted for if one notices that the scientist already has an explanation for the behavior of Jupiter, a scientific explanation, and a perfect one at that, for it is in terms of the process knowledge provided by Newtonian mechanics. In the case that Jupiter flies out of its (predicted) orbit at a tangent the astronomer expresses wonder. The presence of wonder indicates, according to Toulmin, that Jupiter is behaving "unnaturally." The astronomer's wonder is equally well accounted for if one supposes simply that such behavior is not what is predicted by the scientific explanation the astronomer believes that he has; that is, the explanans (initial conditions plus process law) predicted one thing which turns out to be false, showing that at least one of the sentences in the explanans is false, and that therefore the explanans must be revised, and replaced with a correct scientific explanation.

Clearly similar comments can be made about the action of the car. Except that in this case the knowledge involved is imperfect. This would require by now obvious modifications in the account in terms of laws of the absence and presence of wonder in the observer ([6], pp. 249 ff.).

I conclude that the ordinary examples do not establish Toulmin's case for reviving the Aristotelian patterns.

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