CAUSALITY IN SCIENCE

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ABSTRACT

The concept of causality understood as law-like regularity, pervades science from the applied or practical to the theoretical sciences, from its early days to the present. But, workers like Russell and Hanson have correctly observed that explicit mention of causes tends to disappear in advanced and strictly theoretical sciences like physics and gravitational astronomy.

The concept of prediction or explanation in accordance with general laws, replaces the earlier causal concepts. The limiting form of this process is a science where Hempel-Oppenheim explanation is achieved. Here the controversial symmetry between explanations and predictions, as implied by Hempel's view, does exist even if it does not in a more primitive scientific work. Only quantum mechanics casts doubts on this thesis, but contrary to views advanced by Hanson, the symmetry thesis can be extended into that discipline.
ACKNOWLEDGEMENT

After receiving my Bachelor of Science degree, I went to see Professor Barnett Savery, the head of the department of philosophy. I was very fortunate to find a real philosopher whose guidance in a genuine philosophical spirit gave me encouragement. In his department under the guidance of Dr. Ian Hacking, I have completed the work I present here, on the question of causality in science. It was a pleasure for me to be introduced by Dr. Hacking into independent philosophical thinking.
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ON CAUSES IN PRACTICAL SCIENCE

In giving the cause for a particular occurrence both in everyday affairs as well as in practical science, we are making a statement which may be put in the form: 'whenever X then Y'. The initial condition X has to be a sufficient condition for the occurrence of Y. One may distinguish between two interpretations (i) X determines Y in the sense of having the power to bring about Y. (John Locke spoke of the idea of cause as the idea of operation with something operating which we call a cause.)\(^{(1)}\) (ii) X and Y are related in the Humean sense of constant conjunction.

In a Humean account, any talk about Y's occurrence is incomplete for we must determine how X and Y relate; how precedent occurrences relate with consequent occurrences according to a law. This is exactly what a more advanced science does. On the other hand causes 'having power' is a pre-critical manner of speaking for the 'power' is a postulated occult quality.

An inquiry into understanding the world which is restricted to causes in incomplete in that the form or the functional relationship between antecedent and consequent occurrences is omitted. I will now turn to an investigation of causes in practical science to illustrate how causes are used and to illuminate this incomplete or fragmentary description of nature.

In 1910, Bertrand Russell\(^{(2)}\) sharply criticized the notion of causality noting in particular that causes are excluded from advanced science. However, the word 'cause' continues to be used in spite of its omission from theoretical science. The medical doctor will say, "Deprivation of ascorbic acid causes..."
scurvy"(3) according to this usage it seems that the cause is the lack of some essential ingredient. The consequent condition of good or bad health is related to a set of antecedent conditions in a relationship of the type

(1) if A, B and C then G (good health)

(2) if not A, or not B or not C, then not G (poor health).

Usually in talking about the cause of some effect, we talk about the presence or occurrence of some event, or possibly body which may act as an agent, in the production of the effect; that is, we talk in terms of type 1 above. However, in practical science, the notion of cause is not restricted to (1). This seems to imply that the notion of agency is not essential to the concept of cause in this usage.

If someone said that cause always involves agency, even in the case of 'lacks', he might counter my claim by saying that, "To say that lack of A causes B is to say that there is an agent C that causes B but would not cause B in the presence of A."

It is clearly the case that 'cause' is used in sentences of the form 'lack of A causes B'. What is in question is: if such an agent can be found, what is the status of the agent? Can we identify this agent and observe in an experimental situation whether or not the agent operates in the presence or absence of A? If not, is the agent merely a postulation having no independent grounds for its existence other than satisfying the need to have an agent always acting as the cause?

The problem becomes easier by considering the example, "Deprivation of ascorbic acid causes.....scurvy". Modern medical knowledge does not reveal the presence of an agent which causes
scurvy in cases where ascorbic acid is lacking. Such an agent would have only postulational status.

Let us try to build as strong a case for the 'agency theory' as possible. On being told that the lack of nutritious food causes diseases, the advocates of agent as cause would point out that 'in the absence of nutritious food there are agents, bacteria, which cause ill health', (infectious bacteria attack the weakened organism). Bacteria can be identified more specifically on independent grounds as causes of illnesses. The presence or absence of particular bacteria is related to the presence or absence of some particular illness.

In using language, we call both 'bacteria' and 'lack of nutritious food' causes, choosing one in preference to the other depending on which is more accessible to manipulation in a particular experimental situation, or choosing one in preference to the other depending on which level microscopic or macroscopic we wish to make our analysis.

To maintain or even to understand the thesis that 'cause must be an agent', it is important for us to note in particular the status of an agent as cause. That is, ill health can be given a number of causes among them a cause which is recognized as an agent. There are no grounds for the statement that only agents are causes where the causes of some event are spoken of as lacks, agents or states. Turning to our previous example, 'bacteria cause caries', we may ask, 'how do bacteria cause caries?' To ask for what purpose (why) bacteria cause caries is simply teleological. Such questions are excluded from science. A complete answer to the 'how' question will involve us in the
metabolism of bacteria and chemistry of bacterial action, and the chemistry of the body. No agent here. Then just as 'cause' in the sense of lack was found to be incomplete, so also 'cause' as agent is incomplete in so far as further analysis does not rest content with bacteria as agents.

In ordinary discourse, we may ask "Why did Mr. X get up and leave the table before dinner was finished". Two distinct types of answers are often given. In terms of purpose, Mr. X's action could be described as resulting from his desire to hear the news. Then his purpose in leaving the table was to turn on the radio. Alternatively, the same occurrence may be described in terms of habit and neural preferential pathways. "Mr. X left the table because the mantle clock 'struck six'." The striking of the clock initiated his response to go to the radio and 'flick' on the switch which he has been doing for the past ten years. In the one case, the action resulted from the motive to achieve a certain end. The other answer is causal: a particular external stimulus caused Mr. X. to get up.

Gilbert Ryle objects to motives being causes saying as follows: ".....to explain an action as done from a certain motive is not to correlate it with an occult cause, but to subsume it under a propensity or behaviour trend."(4) The occult cause to which Ryle refers is the faculty of volitions which he vehemently rejects, proposing four types of difficulties which volitionists have to surmount. He concludes: "Motives are not happenings and are, therefore, not of the right type to be causes."(5)

The causal explanation (the one which explicitly mentions a cause), illustrate a primitive type of scientific explanation.
The event 'mantel clock striking six' is related for this particular man to the response 'flicking the radio switch' according to the relationship whenever X then Y. A more complete explanation for this particular occurrence as might be made by a physiologist would be in terms of preferential neural pathways relating stimulus to response without explicit mention of cause.

States are said to be causes in sentences of the following form: 'What caused him to give up the Church?' --- 'Disillusion with the Pope's stand on contraception'. To say that a man is disillusioned is to make a dispositional statement about him in the Rylean sense. "To possess a dispositional property", according to Ryle, "is not to be in a particular state, or to undergo a particular change; it is to be bound or liable to be in a particular state, or to undergo a particular change, when a particular condition is realized". (6)

If A is disillusioned (dispositional), then he is bound or likely to do so and so in such and such circumstances. This is all that is meant by saying that disillusion or love are states. According to Gilbert Ryle's analysis, the general fact that a person is disposed to act in such and such circumstances does not by itself account for his doing a particular thing at a particular moment, any more than the fact that the glass was brittle accounts for its fracture at 10 p.m. as the impact of the stone at 10 p.m. caused the glass to break.

We do, however, use the word 'state' in other contexts than the previously considered dispositional manner. In physics, we talk about energy states of atoms. "Bohr suggested that,
inasmuch as Planck had already shown that the classical theory
did not adequately describe the interaction between radiation
and matter, it was reasonable to assume that there were certain
stationary states in which an atom did not radiate at all.
Each of these states is characterized by a definite energy.
They are separated by finite energy. They are separated by
finite energy differences. Emission and absorption of radiation
take place when the atom makes a transition from one state to
another". (7) In what sense can the higher energy state be
said to cause the emission of radiation? By higher energy
state we mean a 'state' above the normal state of lowest energy.

To talk about atomic states is to talk in the hypothetical language -- if.....then. The state of an atom cannot
be identified apart from the absorption or emission of photons.
If we are treating the emission or absorption as effects, then
the cause cannot be identified on independent grounds. Furthermore, although an atom which is said to be in a particular
excited state (i.e. the first excited state above ground state),
eventually decays with the emission of a photon with a unique
energy associated with that transition, the time at which this
transition occurs is indeterminate. Only the half life for
some particular state is knowable.

Classically, if A is in a state S, then something
is still required to initiate an action; the state predicts
the type of response. It does not initiate the occurrence of
the effect. To say, then, that the state of an atom is the
cause of the emission of some particular photon is to make two
serious errors. Firstly, it is to introduce an occult cause.
Secondly, it is to say that the cause of some effect can con-
tinue to exist for some unspecified time without producing the
effect. It is to say something similar to 'the cause of the
breaking of the glass was its brittleness'.

There is a further common use of 'cause' as state.
We often say: 'the warm weather, (a state), caused the snow
to melt.' This is equivalent to saying, 'The snow melted because
of the warm weather'. We often also reverse the order and say,
'I know it is warm because the snow is melting'. The fact is,
to say 'it is warm', is to say the snow is melting, my hands
are not freezing, etc. Warm and cold, of course, are words
whose meaning varies according to context. In summer, 65
degrees Fahrenheit is cold; in winter, it is warm. But as we
ordinarily use these words, we assume the pertinent context.
'On waking one winter day I look out the window and see the
snow melting. I exclaim, It's warm outside!' In the relevant
context, to say 'it is warm' is to imply that 'the snow is
melting'.

The question now remains -- Do we mean anything more
than the above when we say that the warm weather is causing the
snow to melt. The two possibilities are:

i. warm weather is a causal agent

ii. warm weather explains the melting of the snow
    in the same sense that acids in the mouth explain
    tooth decay in terms of the concepts of physics
    and chemistry.

We can reject i. outright as a misuse of 'agent'.
ii. carries the force of a law explanation.
As we have seen from the previous analysis, the question 'What caused it?', is often answered by an explanation of 'how it occurred'. This appears to be the most complete answer in so far as such explanations take into account all features which appear essential for its production. Often, these explanations are given in terms of laws or rules. But, there is something strange about saying that rules cause effects (events). Rules are made by men. They are spoken or written. They are not in the world, for they have no temporal or spatial location. Nevertheless, asking for a cause turns out very often to be asking for an explanation. N. R. Hanson goes as far as to say that, "The primary reason for referring to the cause of X is to explain X. There are as many causes of X as explanations of X."(8)

Let us suppose that there are n possible explanations of a car accident. Further investigation reveals to the magistrate that according to 'rational' considerations, two of them are unsatisfactory. Now, having all the pertinent 'facts' before him, he advances a new explanation for the accident. Are we then to say that first there were n causes, then there were n-2 causes, and now there are n-1 causes for the accident? It is clearly the case that 'causes' and 'explanations' do not have a one-to-one correspondence. I believe that we will all readily admit that the explanations for the occurrence of some event may be many, may differ from day to day and may be correct or not correct. However, causes cannot be treated in this way. The causes for yesterday's accident are not different today from yesterday. Neither are causes said to be correct
or incorrect, although, the cause of some event may or may not be correctly indentified.

What does Hanson mean by 'explain'? We often ask, 'Explain why.....?' and 'Explain how.....?' To 'explain why' in its primary sense is to give purposes, motives and reasons. To 'explain how' is to give descriptions, origins or to invoke some theory of operation or some model.

Suppose someone were to say that there is a one-to-one correspondence between the correct explanations and the causes for some particular occurrence. To refute this assertion, it is sufficient to point out that 'why' explanations are made in terms which, as we have seen, are not causes.
"WHY QUESTIONS" CORRESPOND TO CAUSES
AND "HOW QUESTIONS" CORRESPOND TO LAW-LIKE EXPLANATIONS

Even though questions in science may be formulated in terms of 'why', yet these questions are never answered by stating purposes or teleological reasons. The answers which science gives to 'why' questions are never in terms of purposes or reasons but in terms of how X varies with Y; how the atmosphere scatters white light, how the plant synthesizes sugars, etc. I believe 'why' remains in use since pre-scientific thinking was often teleological and involved agents as causes with power to bring about their effects. So in former times 'why questions' were appropriate. The word has remained with us although we no longer use it in its teleological sense in science.

It is important for us to be clear about (the contrast between) the 'how' and 'why' type questions because the change from 'why' to 'how' corresponds to a change from a system of causes conceived as what Locke calls 'powers' to a system of law-like statements about the world. Where causes are thought to have the power to bring about their effects 'why' questions are appropriate. 'Why did P occur?' Answer: X had the power to produce P and X was present i.e. X caused P. On the other hand the question: 'How did P occur?' is not satisfactorily answered by saying 'X caused P'. We can ask how did X cause P?' or, 'what is the exact relationship between X and P?' What is being asked for is the law relating to X and P.

We can even begin to date the change between the two conceptions. Ernst Schumacher writing on Galileo's method for
conducting investigations in natural science says as follows:

"Galileo replaced the unfruitful speculations of 'why?' by an analysis of 'how?' He recommended that the investigation of nature should no longer continue to inquire into its substance but rather into its function; the investigations should concern themselves not with the essences but with the attributes of nature. Galileo characterized this new method of viewing nature in the third letter on sunspots to the mayor of Augsburg, Markus Welser, dated 1613." (9)

I quote in part from this letter:

"For in our speculating we either seek to penetrate the true and internal essence of natural substances, or content ourselves with a knowledge of some of their properties. The former I hold to be as impossible an undertaking with regard to the closest elemental substances as with more remote celestial things... I know no more about the true essence of earth or fire than about those of the moon or sun..." (10)

P. H. Nowell-Smith* writing on causality says much the same thing:

"The transition from explanations in terms of efficient causes to explanations in terms of Law was largely the work of Galileo... In the first place he undermined Aristotelian explanations of why things move as they do... This discredited the whole enterprise of explaining phenomena in terms of final causes and thereby opened the way for other types of explanation. Secondly, the substitution of exact description for explanation (or, as it is sometimes put, of the question 'How?' for the question 'Why?') led eventually to a conception
of science in which all explanation just is description. A phenomena is now said to be explained when the regularity which it exemplifies is able to be incorporated into a system of laws..."(11)

The analysis of 'how' and 'why' questions serves as an explication of the Schumacher and Nowell-Smith views which are of paramount importance for understanding the relationship between the two world accounts: (i) in terms of causes, and (ii) in terms of descriptions as law-like accounts of the world. I wish to make this separation of 'why?' and 'how?' which establishes the method of science clear. Let it be understood, that the following discussion of 'why?' and 'how?' does not attempt to be a thorough language analysis, but it is rather restricted to clarifying the concepts of purposes and reasons as associated with 'why?' and 'how?' questions in so far as they have bearing on my thesis.

Anatol Rapoport notes the contrast in the tasks of philosophy and that of science.

"Science confines itself to descriptions of how things happen and does not pursue the more fundamental question of why things happen as they do. It does remain for philosophy to investigate this more fundamental question."(12)

Whereas, science will answer 'why' questions, it will do so by stating that some particular occurrence falls under the form of a general law. In answer to the question, 'why did the apple fall?' science will say, 'because all bodies are attracted towards each other in accordance with the universal law of gravitation'. To the question 'what caused the apple to fall?' the same answer will be given. Essentially, science answers only one question and tha
is the 'how' question, namely, 'How do bodies fall?' They fall in accordance with the universal law of gravitation.

I wish to distinguish between two uses of 'why'.

Ia. Why did Brutus stab Caesar?
   b. Why did President John Kennedy declare a war on poverty?

Here the answer is given in terms of the purposes or motives which the subject is said to have had.

a. His purpose was to conserve the Roman Republic from the imagined usurper Caesar.
   b. His purpose or motive was to build a strong and just America.

The second use of 'why' is illustrated by the following two sentences:

IIa. Why did the wine bottle which one of Caesar's soldiers threw into the Tiber at the left bank end up on the other side of the river?
   b. Why is the sky blue?

We note, first of all, that the sentences Ia. and b. change their meaning when 'how' is substituted for 'why', or 'how did it occur that' is substituted for 'why'. That is - "How'did Brutus stab Caesar?" or "'How did it occur that' Brutus stabbed Caesar?" asks for the historical recreation of the physical event, or it asks for the preceding events which led to the stabbing. Similarly Ib. with the substitution of 'how' for 'why' now asks for an observer's account for what went on at that historical occasion.

I will refer to the use of 'why' which does not allow a 'how' substitution as the unique use. There is also a unique
use, in the same sense, for 'how', as we shall see, where 'how' cannot be replaced by 'why'. Namely, the question, "How does that mechanism work?", is answered by explaining how its various parts interact. The question, "Why does the mechanism work (like that)?", is answered not 'how' the mechanism works (since the implicit 'like that' already implies knowledge of 'how'), but rather, "What did the maker of the machine or mechanism have in mind for it?" Possibly, we can make this even clearer. Consider the sentence, "How far is the moon?" Operationally, what is being asked here is, "How many measuring sticks have to be laid out to cover the distance separating the moon and the earth?" or for some more advanced variant of this. It is clearly nonsensical to rephrase the question to "'Why' far is the moon?"

In IIa. substituting 'how' or 'how does it occur that' for 'why' does not change the meaning of that sentence. In IIb. "Why is the sky blue?" or "How does it occur that the sky is blue?" are sentences which are not commonly used in the English language. One is not exactly clear what is being asked. The force of IIb. appears to be: "In virtue of what process is the sky blue?"

Let us assume that we are asking a scientifically orientated person why the sky is blue. Then we would presumably be told something like: The light from the sun, white light, is a mixture of the various spectral colours, but the atmosphere scatters the shorter wave length (blue) more than the longer wave lengths. Consequently, we observe the sky as blue. Now, if we consider this answer apart from the question which we asked, we see it as an explanation for the blueness of the sky. In particular, we see that the explanation describes how white light
originating in the sun is scattered by the earth's atmosphere. We are not told why any of this happens. That is, the explanation is an answer to a 'how' question; although the question which asks "How does it occur that the sky is blue?" is not commonly used. The 'why' question is a remnant of a teleological pre-scientific conception of the world.

To conclude: The unique use of 'why' which does not allow an alternative 'how' question to do its work is in terms of purpose, motives, reasons and possibly final causes, involving agents. Similarly, 'how' has a proper use which does not overlap with the 'why' question. In using language, we often ask 'why?' but do not distinguish this 'why' question from the same question with 'how' substituted for 'why'. Where 'why' questions are asked in science the answer is always in terms of 'how', whether or not, as the illustration which we have considered shows a direct 'how' substitution is in common acceptable use.
CAUSES IN C. G. HEMPEL'S EXPLANATIONS

Carl Hempel and Paul Oppenheim writing about explanations divide the basic pattern of scientific explanations into two constituent statements, explanandum and explanans. The explanandum describes the phenomenon to be explained and the explanans accounts for the phenomenon.

"The explanans falls into two classes, one of these contains the sentences $C_1, C_2, \ldots C_K$ which state antecedent conditions and $a_1, a_2, \ldots a_r$ which represents general laws."(13)

Four logical conditions of adequacy are given as follows:

(1) The explanandum must be logically deducible from the information contained in the explanans.

(2) The explanans must contain general laws, and those must actually be required for the derivation of the explanandum.

(3) The explanans must have empirical content i.e. it must be capable, at least in principle of test by experiment or observation.

(4) The explanans has to be highly confirmed by all relevant evidence available.

"An explanation is not fully adequate unless its explanans, if taken account of in time, could have served as a basis for predicting the phenomena under consideration."(14)

The Hempel-Oppenheim view of the relation of explanations to causes are clearly brought to light in the following quotation:

"If E describes a particular event, then the antecedent circumstances described in the sentences $C_1, C_2, \ldots C_K$ may be said jointly to 'cause' that event... Statements such as
a₁, a₂...aᵣ which assert general and unexceptional connections between specified characteristics of events are customarily called causal or deterministic laws."(15)

The causality, which has been described in natural science, is not occult or unknowable. This causality is founded upon answers to 'how questions'; in the previously considered sense, not 'why questions'. "How questions", are answered i.e. explanations are given in science by showing that the particular occurrence of some event is predicted or its occurrence follows in accordance with general laws from some earlier (earlier in the derivation) situation. From the preceding discussion it should be clear that it is not the aim of theoretical science to discover causes. The causes for some particular occurrence are the situations C₁, C₂...Cᵦ from which by means of the laws a₁; a₂...aᵣ the consequences or effects can be logically deduced.

In this connection it is of interest to note the 19th century physicist Kirchhoff's views:

"In his work on mechanics he declares that it's objective is not to discover the causes of motion; it is to describe completely and in the simplest manner the motions which occur in nature under specific conditions."(16)

As we have seen, Hempel claims a symmetry between explanations and predictions. I wish briefly to inquire here, 'what are explanations?' The function of explanation is clearly as Michael Scriven says to provide understanding.(17) Yet, understanding is not always a consequence of an explanation (we say I just don't understand his explanation for the occurrence of X). Nor is it required that explanations always be given for
understanding to result. If I was told that a wet air front was moving in from the sea I would understand why it is raining. That is, given certain facts pertinent to X we can often understand the occurrence of X. An explanation is not given. Yet, in a sense an explanation is made. In order for an explanation to be given it would be required that a derivation be made in accordance with general laws, from some given situation, this constitutes the explanans statement.

Given the fact that moist air is moving in from the ocean and knowing the law that: Whenever moist air moves in from the ocean it is forced to rise over the mountains thus cooling the air and forming precipitation, we can understand why it is raining in this particular situation. (We can understand what processes have taken place or are taking place.) Such understanding required a knowledge of how rain is brought about and a knowledge that the requisite conditions are here and now realized.

Do we in general require that laws should be invoked for an explanation or is it sufficient for an explanation to be given when a particular is subsumed under an empirical generalization? Is it an explanation to answer the question, "Why did this pen fall down?" by saying that under a set of boundary conditions all material bodies fall? The generalization "all bodies fall" requires us to know that the particular object under consideration does so also i.e. that this pen does so also. If the particular body under consideration is included then the premise already assumes that which is to be deduced.
The previous considerations suggest that an explanation in terms of a particular occurrence falling under a universal is faulty. But, often, just such explanations are useful and are in fact accepted as sufficient explanations. The assertion that: "His 1953 Chevrolet 'broke down' when the recorded mileage was in excess of eighty thousand miles." may be considered as being explained by showing that all known automobiles of this make do in fact 'break down' after being driven in excess of eighty thousand miles.

Regarding the Aristotelian syllogism J.S. Mill writes:

"The inference is finished when we have asserted that all men are mortal." (18)

It appears that Mill is correct in saying we perpetually reason from particulars to particulars. The particular men we know to have died serves as a reason or basis for saying that some particular living man is mortal. The intermediate general proposition may be construed as serving or functioning as a statement for some finite sampling of individuals from which, in fact, the reasoning to some other particular is made.

Alternatively, we can view the premise, "All men are mortal" as being asserted with a high degree of probability conditionally upon the stated premises. This latter interpretation is consistent with the Hempel thesis in that a general proposition is used in the explanans.
EXPLANATIONS AND PREDICTIONS IN QUANTUM MECHANICS

In the realm of theoretical science Hempel's symmetry between explanations and predictions does seem to exist. Only quantum mechanics casts serious doubt on this thesis, but contrary to views advanced by N. R. Hanson, even quantum mechanics displays this symmetry.

N. R. Hanson in an article ON THE SYMMETRY BETWEEN EXPLANATIONS AND PREDICTIONS attacks the Hempel thesis that, "the justification of a prediction of P is symmetrical with the explanation of P." He says "Only in Newton's PRINCIPIA MATHEMATICA PHILOSOPHIAE NATURALIS does the final ideal which Hempel outlines seem fully to be realized."(19) Hanson looks to quantum physics to find a counter example or a realm of exception to Hempel's conception of explanation in science. He writes,

"The situation is, however, totally different in quantum physics...given any single quantum phenomena P (for example, the emission of a $\beta$-particle from a radioactive substance or the scattering of a $\gamma$-ray photon by an electron), P can be completely explained ex post facto; one can understand fully just what happened, in terms of well established laws of the composite quantum theory... These laws give the meaning of explaining single micro-events... But it is, of course, the most fundamental feature of these laws that the prediction of such a phenomenon P is, as a matter of theoretical principle, quite impossible."(20)

Hanson repeats this same claim in the article THE COPENHAGEN INTERPRETATION OF THE QUANTUM THEORY(21) again without offering any argument for the claim that quantum physics 'explains'
individual micro-events.

To meet Hanson's objections we may follow two routes. We may with Einstein, DeBroglie, Schrodinger and more recently (1957) with Bohm\(^{(22)}\) argue that quantum mechanics is not complete i.e. that further study will reveal hidden parameters which will allow predictions to be made of the behaviour of individual fundamental particles. Alternatively we may question whether or not in fact quantum physics does explain individual phenomena in a sense in which it does not predict these phenomena. I wish to pursue the second line of objection, that is, to inquire in what sense quantum physics explains and to inquire if there is not a corresponding sense of prediction.

N. R. Hanson writes, continuing his criticism of the hidden parameter view, "There is no intelligible way in this system (wave mechanics) of speaking of the position of a high speed electron and there is no way in this system of forming predictions of certain types of events (for example, neutron emission from unstable carbon)."\(^{(23)}\) This view or understanding of quantum mechanics does not differ in essence to Linus Pauling's conception. Pauling writes,

"Schroedinger's system of dynamics differs from that of Newton, Lagrange and Hamilton in its aim as well as its method. Instead of attempting to find equations which enable a prediction to be made of the exact positions and velocities of the particles of a system in a given state of motion, he devised a method of calculating a function of the coordinates of the system and the time (and not the momenta or velocities), with the aid of which, in accordance with
the interpretation developed by Born, probable values
the coordinates and other dynamical quantities can be
predicted for the system."\(^{(24)}\)

I wish to consider the physical (Born) interpretation
of the Schrödinger wave function\(\psi\). In the one dimensional
case \(\psi\) is a function of \(x\) and \(t\), i.e. \(\psi(x,t)\). For a given
value of the time \(t\), \(\psi^*(x,t)\psi(x,t)\), i.e., the product of
and its complex conjugate, is a function defined for all
values of \(x\) between \(-\infty\) and \(+\infty\); that is, throughout the con­
figuration of space of this one dimensional system. It is the
Born postulate that: "The quantity \(\psi^*(x,t)\psi(x,t)dx\) is the
probability that the system in the physical situation repre­
sented by the wave function \(\psi(x,t)\) have at the time \(t\) the
configuration represented by a point in the region \(dx\) of the
configuration space."\(^{(25)}\) \(\psi^*(x,t)\psi(x,t)dx\) is the probabi­

But in talking about particles or waves we are talking
about macroscopic concepts. The solution to Schrödinger's
equation for a free particle is of a sinusoidal character. Wave
functions as obtained by a solution of Schrödinger's equation
"give rise to experimental phenomena which are closely similar
to those associated in macroscopic fields with wave functions.
Neither view (particle or wave) is without logical difficulties,
in as much as waves and particles are macroscopic concepts which
are difficult to apply to microscopic phenomena."\(^{(26)}\) The reason
for adhering to the particle concept in wave mechanical calcula­
tions is simply to give a good intuitive feeling for the
mathematical results.
The fact is that quantum mechanics (the mathematical structure) does not explain individual events any more than it predicts individual events, not because of some limitations in the theory but because the particles aren't there. Both particles and waves are macroscopic concepts.

We can force Hanson into a dilemma. Either (i) the phenomena of experience are explained by quantum mechanics or (ii) the phenomena of experience are explained in terms of the concepts of classical physics in which meaning is given specifically to the concept of a particle at a point i.e. space at a given time i.e. $P(x,y,z,t)$. If (i) is adopted then individual events (clicks on a Geiger counter) cannot be explained in terms of quantum mechanics. Individual events said to be occurring at $P(x,y,z,t)$ are not quantum mechanical concepts. Alternatively if we adopt (ii) then meaning is attached to the concept of a particle at $(x,y,z,t)$. But, classical mechanics is not competent to deal with microphysics. Attempts at explaining black-body radiation and the photo-electric effect showed the limitations of classical mechanics. The quantum mechanical description of a particular particle according to the Born interpretation is just the $|\psi|^2$ probability function solved with some specified initial conditions.

Suppose we are asked to explain the diffraction of electrons by a crystal. A detector placed at a certain angle indicates that electrons are being received - what is the explanation for this observation? To account for the observation we assume that what is called beam of electrons viz. a wave of frequency $\nu = \frac{E}{h}$ falls on the crystal, and we calculate the
intensity of the waves scattered in the direction specified. The result of such a calculation indicates within limits what the detector is expected to record. It indicates angles of high probability and low probability for finding electrons.

It is the case, as Hanson says, that predictions of individual quantum phenomena are quite impossible, but so are also explanations. Hanson says that the symmetry thesis is violated, since "...a Geiger counter intercepting $\beta$ particles from an unstable isotopic source will click in a wholly unpredictable way. Once a particle has been emitted the counter's click is determined classically. But it remains conceptually untenable to predict when a particle will be emitted, and hence when the counter will next click... Its macrophysical clicks must be in principle unpredictable."(27) Hanson's main effort is directed to denying the hidden parameter view. My thesis does not require a defence of the hidden parameter view.

Whereas it is quite clear what quantum mechanics does not predict it is not clear what quantum mechanics is said by Hanson to explain and what in fact it does explain. On page 31, CONCEPT OF THE POSITRON, he says:

"A quantum theoretic account of these phenomena (single neutron emission from unstable carbon) does explain, to a considerable extent, what kind of physical events they are." From the preceding two quotations it appears that quantum mechanics is required to explain

(i) the unpredictable clicks on a Geiger counter
(ii) the emission of neutrons (particles) from radioactive material.
To maintain his thesis, then, Hanson must claim that both (i) and (ii) are explained by quantum mechanics. It is clearly not sufficient to say as Hanson does in the preceding quotation "explained to a considerable extent" for then to maintain the symmetry thesis we would only have to say "predicted to a considerable extent." Hempel suggests only that the symmetry is between complete explanations and predictions. Let us turn to Hempel's own answer to Hanson's criticism:

"If the information that P has occurred were included in the explanans, the resulting account would be unilluminatingly circular... And if the explanans contains only statements about antecedent conditions, plus a statistical law of radioactive decay, then it can show at best that the occurrence of P was highly probable; but this affords only an inductive-statistical explanation, which has the same logical form as the probabilistic i.e. inductive, prediction of P." (28)

Hanson does not, apparently, want to restrict himself to a specific statement of what he means by 'explain'. The following he does say about explanation. Aristotle's cosmology made the cosmos "more intelligible to his contemporaries and, in some sense this must count as 'explanation'." (29) Hanson is particularly interested in what have counted as explanations in the past, for example, Leibniz did not think the PRINCIPIA offered explanations but served only as a mathematical predicting device. To 'explain' in the past, suggests Hanson, has been used as meaning: to relate to the intuitively evident. 'Post diction' does not always satisfy these conditions.
On page 1 in the introduction to the CONCEPT OF THE POSITRON Hanson writes, "The 'hole-theory' of the positive electron is an explanation of things like pair creation and annihilation; none the less, as a matter of principle, this theory cannot predict when any given pair will be created." Unfortunately Hanson does not further elaborate, in his writing, exactly how this theory 'explains'. The few words devoted to the subject present an analogy with a concrete situation. It is not at all clear what constitutes the explanation.

Continuous $\beta$ emission spectrum is said to be explained by postulating neutrinos. Neutrinos are given the properties charge = 0, rest mass = 0, linear momentum = $P$, relativistic energy = $PC$, and angular momentum = $\frac{1}{2} \frac{h}{2}$ which are required to explain the continuous $\beta$ spectrum. On page 124 Fermi is quoted as saying:

"The whole story about fundamental particles is that they show themselves to have just those properties they must have in order to explain the large-scale phenomena which require explanation... The existence of the neutrino has been suggested as an alternative to the apparent lack of conservation of energy in $\beta$ disintegration." What is to be explained here is the observed continuous $\beta$ spectrum. This is done by postulating a new particle which carries off the energy which has to be accounted for in order to satisfy the conservation of charge, mass angular momentum and energy. Given this microphysical structure it seems clear that an explanation for the observed continuous emission spectrum is found in microphysics.

I believe, however, that one can predict a continuous
\( \beta \) spectrum where we know that the energy lost in the atomic disintegration would be shared between two particles (the postulated neutrino and the electron) according to some statistical law.

Postulates are often made in science to aid in the explanation of phenomena i.e. the postulated neutrino allowed an explanation to be made of the continuous \( \beta \) emission spectrum. Yet, it is important to note the status of postulated entities. Let us consider another postulate. It was observed early in the physical work on heat that 'heat energy' transfer could be easily understood by postulating that heat was a fluid (caloric). Such phenomena as temperature equilibrium of two bodies in contact could with this postulate be readily understood in terms of the more familiar properties of fluids. Then to explain why two metal bars, one at a higher temperature \( T_H \), the other at a lower temperature \( T_L \), reached an equilibrium at some intermediate temperature \( T_M \), one would say that this was a consequence of the behaviour of fluids (they seek their own level).

We, however, have learned from the trials of the past what is to constitute a fruitful or significant postulate in science. It is required that such postulates function in future predictions, that future experimental results can be predicted in terms of the earlier postulates. Postulates must not only facilitate in the making of explanations but must also function in predictions. Furthermore we require that coherence should be maintained in the discipline. Introducing the fluid or caloric theory of heat is to introduce inconsistencies in the sense in which we introduce a fluid, caloric, which is in variance with all known fluids in being without weight. (This
is a serious inconsistency in so far as it is no longer understandable how a weightless fluid can seek its own level.)

As I understand Hanson's objection to the symmetry thesis it is simply this: We understand what happens when high energy particles emitted 'randomly' by radioactive matter interact with the measuring device producing a flash which is amplified and recorded. It is quite true that the collision of an electron with an atom which brings the atom to a higher energy level and the eventual emission of a photon is a quantum phenomena which in fact constitutes an "explanation of what goes on in the counter." I believe that this is what Hanson means when he says that quantum mechanics explains individual events. Yet, clearly, this is not the problem with which we are grappling. Consider the analogy; one may understand perfectly well the mechanism or the process that is occurring when it is raining without being in the least aware why it is raining at this particular time and place. This understanding requires prior knowledge of particular air currents, air moistures and temperatures, knowledge which often enough is not available even to the meteorologist. It is possible to know and to explain what is happening when it is raining without being able to explain why it is raining here now.

In quantum mechanics it is precisely the 'here now' which is not explicable.

Hanson claims that there are two consequences of accepting quantum mechanics, neither of which I have any reason to reject and neither of which serves as a criticism of the Hempel-Oppenheim thesis. They are

(i) there is no intelligible way in this system of speaking
of the exact position of an electron of precisely known energy.

(ii) there is no way in this system of forming predictions of certain types of events (individual quantum events).

If there is no intelligible way in this system of speaking of the exact position "how then can it make sense to say there is an intelligible way to explain precisely that which we cannot speak about?"

I wish to turn to some arguments in Ernst Cassirer's DETERMINISM AND INDETERMINISM IN MODERN PHYSICS to make my case stronger. The essential case for indeterminism in Cassirer's account centers on the fact that knowledge of the \( \psi \) function at some time \( t \), as \( \psi(x,t_1) \) allows \( \psi(x,t_2) \) to be predicted for some later time \( t_2 \). The Schrodinger equation can only yield a single-valued, finite and continuous solution. There is nothing indeterminant about the wave function.

Cassirer writes:

"When the theory of radioactive decay declares that for every substance there exists a certain probability that an atom chosen at random will decompose within a randomly chosen interval of time; when it is shown that there is a definite exponential law governing the decay; when accordingly the 'decay series' of various radioactive families are established - then these are all extremely precise conclusions, even though they say nothing about the fate of the individual atom and the precise instant of its decomposition." (30)
The fact that individual prediction is not possible in quantum mechanics, does not establish a counter example to the symmetry thesis. Predictions are possible in quantum mechanics; for example, decay will occur according to a definite exponential law. To ask for a prediction of an individual neutron viz. particle is to ask for something which is not even a quantum mechanical concept. The Born interpretation speaks about the probability of there being a particle in a definite volume. The concept of a particle at a point in space at some time $P(x,y,z,t)$ has no counterpart in quantum mechanics.

Cassirer is in agreement with Planck's statement to the effect that the problem "whether a certain question is meaningful in physics, can never be arrived at a priori but always and solely from the point of view of a given theory, the difference between the different theories consisting precisely in the fact that according to one theory a certain quantity is observable in principle, or a certain question is physically meaningful while according to the other is not."(31) Hanson himself has said that particular $^{14}$C atoms are indistinguishable (within a given theory i.e. quantum mechanics). So also are the fundamental particles. (I think Hanson's reasoning is correct on this point). Within quantum mechanics, individual $^{14}$C atoms are indistinguishable. This is granted by Hanson. It follows in accordance with the Planck-Cassirer view that with respect to the theory, the question which atom emitted the $\beta$ particle is meaningless. Then, quantum theory does not explain the situation of a particular atom emitting a particular electron.
An observation may be made in a 'bubble-chamber' of a track; the track is spoken of as having its origin in the radioactive material which is contained within the chamber. A person possessing other information factual and theoretical i.e. knowledge what the particular radioactive material is and presupposing a model or theory of radioactive decay may make the statement: "A $\beta$-particle was emitted at 12:22, as measured on my watch from the $\text{C}_{14}$ sample." He might further add that some particular $\text{C}_{14}$ atom underwent a decay reaction with the consequent loss of an electron. But the preceding statement cannot be translated into quantum mechanical terms while preserving the macroscopic concept "particle here now."

In the quantum mechanical case the best we can do is assert that \[
\int_V \psi^*(x,y,z,t) \psi(x,y,z,t) \, dv = \text{probability that a 'particle' is in the volume element } \Delta V.
\]

Only a value of the $\psi$ function is defined. This means (Born interpretation) that the explanandum is a probability i.e. the probability that a 'particle' is in the volume element $\Delta V$.

We know the predictions of probabilities are adequately handled by quantum mechanics. For this reason it is clear that Hanson has not constructed a counter example or a realm of exception to the Hempel-Oppenheim conception of explanation in science.

Perhaps the foregoing discussion has missed some essential features of the concept of explanation. We explain the presence of a gas by referring to the behaviour of very small unobservable elastic particles in continual motion. We explain the formation of a precipitate in a test tube by
referring to the interactions of ions. It is M. Scriven's claim that:

"We are committed to explaining macro-phenomena in terms of micro-phenomena and thus must believe that the truths of the macro-level (whether observational or statements about theoretical entities) can be accounted for in micro terms." (32)

He reasons that chemical reactions must be explained in atomic terms since the level to which we turn for an explanation of what we accept 'as basic data' is precisely this level.

Suppose we wish to explain the emission of a neutron, from some piece of radioactive material as recorded on a scintillation counter at some time t. The explanandum is a macrophysical observable phenomenon. The explanans invokes the realm of microphysics. In order to satisfy the Hempel-Oppenheim criteria for explanation, the explanation must satisfy four conditions of adequacy. The first condition states that the explanandum must be logically deducible from the information contained in the explanans. The 'here now presence' of the neutron cannot be explained by quantum mechanics. On the other hand, if the explanandum is stated as the probability of X then the first condition of adequacy is satisfied.

Whereas it may the the case that we explain macro-phenomena in terms of micro-phenomena it does not follow that there is or can be complete explanations, in Hempel's sense, for all macro-phenomena. In fact there does not exist an explanation, in terms of quantum mechanics, for individual events as 'particle here now'.

The Hempel-Oppenheim thesis remains intact.
CONCLUSION

Although causes are explicitly mentioned in science, their use is restricted to the practical sciences. They only give a fragmentary account of the relation between occurrences or events in the world.

Science in general serves to answer 'how questions' as contrasted with 'why questions'. Our knowledge of the world as given by a theoretical science is expressed by what we call physical laws. These laws are not functions of the time, although, of course the laws describe the behaviour of phenomena in time i.e. they allow predictions and retrodictions of future and past occurrences. Hempel has labelled these laws causal.

Quantum mechanics maintains strict causality in the sense that latter states of the $\psi$ function are determinable from its earlier states. It is not surprising that accounts describing individual fundamental particle behaviour are not possible since such entities construed as individual mass points having exact spacial coordinates at an instant are fictions. The implication drawn from this is that causality as understood above, (present states allow knowledge of future states), is preserved.
NOTES

(1) John Locke, ESSAY CONCERNING HUMAN UNDERSTANDING, (Dover Publications, New York), Volume 1, Chapter XXVI, page 434


(5) Ibid, page 113

(6) Ibid, Chapter II, page 43


(8) N. R. Hanson, PATTERNS OF DISCOVERY, (Cambridge, Eng., University Press, 1958), page 54

(9) Ernst Schumacher, DER-FALL GALILEI, (The Case of Galilei, Berlin, 1964, my translation), page 31

(10) Galilei Galileo, DISCOVERIES AND OPINIONS OF GALILEO, (Doubleday edition, 1957, Translated by Stilman Drake), pages 123-4

(11) P. H. Nowell-Smith, ENCYCLOPAEDIA BRITANNICA, (1965 edition), page 106

(12) Anatol Rapoport, OPERATIONAL PHILOSOPHY, (Wiley and Sons, New York, 1965), Chapter 5, page 51


(14) Ibid, page 323

(15) Ibid, page 324


(18) J. S. Mill, A SYSTEM OF LOGIC, (Longmans, Green and Co., London, 1900), Book II, Chapter III

(19) N. R. Hanson, ON THE SYMMETRY BETWEEN EXPLANATIONS AND PREDICTIONS, (The Philosophical Review, 1959, 68), page 351

(20) Ibid, page 351

(21) N. R. Hanson, THE COPENHAGEN INTERPRETATION OF THE QUANTUM THEORY, (Reprinted in PHILOSOPHY OF SCIENCE, S. Morgenbesser and E. Nagel), page 463

(22) D. Bohm, A PROPOSED EXPLANATION OF QUANTUM THEORY IN TERMS OF HIDDEN VARIABLES AT A SUB-QUANTUM-MECHANICAL LEVEL (OBSERVATION AND INTERPRETATION, edited by S. Körner, London, 1957), pages 33-41

(23) N. R. Hanson, ON THE SYMMETRY BETWEEN EXPLANATIONS AND PREDICTIONS, (The philosophical Review, 1959), page


(25) Ibid, pages 64-5

(26) Ibid, page 93


(28) C. G. Hempel, ASPECTS OF SCIENTIFIC EXPLANATION, (Free Press, 1956), page 407


(30) Ernst Cassirer, DETERMINISM AND INDETERMINISM IN MODERN PHYSICS, (Oxford University Press, 1956 edition), page 118

(31) Ibid, page 126

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