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The Nature of Possibility*

Some Meanings of ' Chance ' and ' Indeterminacy '

Dr. Eugene Wigner provided an ostensive definition of a first meaning of ' reality ' by grasping an ashtray and rhetorically threatening to throw it at us. He added, further, that " it is not difficult to provoke an admission of the reality of the ' I '. . ." Dr. Alfred Landé made the same point at the conclusion of his talk, by referring to Dr. Johnson who aimed to demonstrate reality by " striking his foot with mighty force against a large stone, till he rebounded from it . . ." This emphasis on the tangible as a first meaning of ' real ' is both sound and wise. I will do the best I can to carry on this discussion without going beyond such common experience.

I have not the slightest intention of exploring all the meanings of the words ' chance ' and ' indeterminacy.' That each of these terms has at least more than one meaning is clear from the following examples : ' He became wealthy by chance,' e.g., he dug for water and struck oil ; ' You have no chance of getting there on time ; ' ' One chance in a hundred ;' ' Give me a chance !' A familiar instance of indetermination would be : ' The man is not yet sure what to think.' By which we mean that he is not yet determined on some subject. This itself can have several meanings ; for example, that he does not know whether it will rain today or not ; that he has not as yet found the solution to a problem ; that he is still undecided whether he shall act or not ; whether he will do this rather than that ; whether he ought to act or not to act ; ought to do this rather than that, and so on.

The subject of today's meetings is *Determinism*, much the same as what is now called causality. If I have understood them correctly, all the physicists whom we have heard in the course of this symposium agree that the so-called principle of causality does not apply at all levels of what they call real. Our first task will be to agree on what ' causality ' has come to mean.

Originally the Greek word for cause, *aitios*, meant *responsible*, particularly in human affairs. Hence the term *aitia*, *responsibility*, mostly in the bad sense of guilt or blame.[1] Eventually this word acquired the general meaning of ' that upon which something depends

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* This paper was read and discussed during a symposium on the nature of reality in physics, held at Marquette University, Milwaukee, June 1961.

1. The history of the Latin *causa* is much the same, it first deals with human action. Vd. ERNOUT et MEILLET, *Dictionnaire étymologique de la langue latine*, Paris, 1959.

either in being or coming to be.' In modern scientific usage, however, as has been repeatedly pointed out by Bertrand Russell, the word ' cause ' enjoys one single meaning, akin to what Aristotle called the agent cause — although this kinship is debatable. (The kinship is rather between our ' cause ' and what Aristotle called ' form as cause,' chiefly illustrated in abstract and applied mathematics.) It is true that we do speak of ' what a thing is made of,' and that we do use the words ' form,' ' structure,' ' purpose ;' but in present usage neither the *wood* of a wooden table, nor its *shape*, nor *that for the sake of which* a table is made, are spoken of as true causes of the table. There are probably good reasons why this should have happened ; certainly, to equate causality with agency — as in ' I made this table ' or ' I did that ' — seems quite natural and fitting at first. But if we would agree to define cause in the fashion just described embracing material, design and intention, then material, or ' what a thing is made of ' will lead us back to the earliest Greek philosophers who held this to be the principle of all there is. No doubt it is simpler to assign a single name for a single kind of thing. But it is likewise true that for the most part we argue in words which have several meanings employed as if they had, or ought to have, only one. This ignored prenumbra of meaning is the chief playground of sophistry. It is worth bearing in mind, as Da Costa Andrade puts it, not without humor, that " the word represented by ' cause ' has sixty-four meanings in Plato and forty-eight in Aristotle." All the same, the historical fact that the word ' cause ' had so long ago acquired a wealth of diverse meanings may serve as a reminder that, however strong our preference for words with only one, a discussion of causality is hardly likely to enjoy the deceptive simplicity which the Humean treatment lent it. It cannot, surely, be so confined if divergent views of ' what a thing may depend upon ' are to be responsibly discussed.

Whatever our understanding of cause, the view put forth by many that ' causality ' should only mean that the future is predetermined in the past — much in the way Laplace would have it — is plainly a very uncomplicated one. This view is not really new. The Stoics had been seduced by it. Its logical statement would be that all propositions about the future are either determinately true or determinately false.[1] On such an understanding, ' causality ' means utter determinism.[2] Hence, if there are areas in the world

1. Cf. ARISTOTLE, *Peri Hermeneias*, 18 *a* 30 — 19 *b* 5.

2. If deterministic causality were understood as a mere principle of method — meaning that where indeterminacy appears in physics we must be ready to attribute this to our ignorance — such a principle would be sound provided it allowed that this is not necessarily the case. In other words, we must likewise admit a principle of indeterminacy as a complementary principle of method.

of the physicist where such ' causality ' does not prevail, it appears that in those areas things occur without a cause.

A good number of contemporary physicists are aware that the matter is not so simple as all that. I have in mind both the Copenhagen school on the one hand, and on the other, Prince Louis de Broglie and David Bohm (both trends have been presented in this symposium). Although they are at loggerheads in their interpretations of the relations of indeterminacy, they all reintroduce into the philosophy of physics the ancient distinction between necessity and contingency. Heisenberg, for one, in his Gifford Lectures, maintains that we must again distinguish in nature the possible from the actual, and he repeatedly refers to what he calls " Aristotle's *potentia* " (cf. *dunamis* or *dunaton* or *endechomenon*). If his reference is to have meaning, we must understand what he intends and what particular meaning of *potentia* in Aristotle may correspond to what Heisenberg expresses. At first sight, the distinction between possibility and actuality seems trivial : when something is actual it must have been possible before becoming actual, for example, yesterday it must have been possible for the sun to rise today. That is not the kind of possibility which Heisenberg seems to intend ; he is concerned rather with the kind of possibility which, to retain our example, we see when we consider that if it is possible for the sun to rise, it must be simultaneously possible, however unlikely, for the sun not to rise. This is what Aristotle meant by ' *potentia* ' in his *dunamis hama tès antiphaseôs*,[1] and it may be worth fastening awhile upon this meaning.

The ' *potentia* ' in question refers, we said, to a simultaneous possibility of contradictories. Thus, since it is possible for me to stand, it must be possible for me not to stand. If there were for me no possibility of standing, so that the only possibility for me were not to stand, the latter ' possibility ' would be the same as the ' possibility ' first mentioned. In other words, it would be false to say that it is possible for me not to stand if it were not also possible for me to stand. What all this forces upon us is the distinction to be drawn between ' possible ' as opposed to ' impossible ' and ' possible ' as opposed to ' necessary.' Now these two oppositions are not opposed one to the other, because the ' possible ' opposed to the ' necessary ' is included in the ' possible ' opposed to the ' impossible.' I mean that both the ' necessary ' and the ' possible ' opposed to it are equally opposed to the ' impossible ' ; were the ' necessary ' not ' possible ' as opposed to the ' impossible,' it would plainly be ' impossible.'

If I understand Heisenberg correctly, the ' possible ' to which he refers is the one opposed to the ' necessary,' namely the said

1. Vd. ARISTOTLE, *Metaphysics*, IX, 1050 *b* 9.

potentia simul contradictionis. There is no room for such potency in determinism ; indeed, determinism might well be described, I think, as an implicit negation of the simultaneous possibility of contradictories.

However, it is important to be aware that the validity of this type of possibility as applied to the physical world is entirely independent of Heisenberg's own principle of indeterminacy. I am part of the physical world as much as any stone. In fact I weigh approximately eleven stone, and there is too much discrepancy between my temperature and the present one in Milwaukee. Now, I feel quite certain that it is possible for me to stand or not to stand — with all due qualifications. When I say this, I do not refer to the active indetermination which is that of my will and allows me the choice. What I do have in mind is the possibility of my body to be in such a position or not. If there were no such possibility in what the physicist describes of me, could I neither choose to stand nor not to stand. When I in fact did stand it would not have been possible for me not to stand, or again when I in fact did not stand it would not have been possible for me to stand. Now, the same applies to the stone with reference to me, inasmuch as it can be picked up by me or not (let it not be too large a stone). In other words, there must be in nature a simultaneous possibility of contradictories. How far this goes, I do not know ; but I insist that I am part of nature and that there are other things in nature which, whether alive or not, yet contain this type of possibility, at least to the degree in which they are open to my activity or inactivity about them. Such a possibility I know by an experience as certain as the one that informs me that there are stones — though I should beg you not to press me too hard on what stones are.

The mere need of recognizing such an experience apparently creates an uncomfortable situation in the world of mathematical physics. In mathematics, of course, simultaneous possibility of contradictories is quite irrelevant, but then mathematical physics is not just mathematics. The examples I have given may serve as indications of the difference between the two. Physical things cannot be fully reduced to abstract quantity nor is it enough to ' reify ' the mathematical to account for the physical.

Curiously, this is implicitly acknowledged even in the context of the principle of causality understood as entailing a future utterly predetermined in the past. For the notion of efficiency, of agent cause, is entirely foreign to mathematics as such ; while this principle of causality was indeed intended to subject nature to a rigour equal to that of mathematics itself. Now if, in nature, what is prior in time necessitates whatever comes after, this ' necessity,' to be valid, must be subject to experimental verification. Verification of a sort can be achieved under certain limited conditions, granted innumerable

provisoes. These conditions and provisoes will show that the principle in question, when taken as universally necessary, applying to all particular events, is actually tautological.[1] Thus we can say that a body of a given weight and size will fall to the earth in a straight line, at a given time, in a certain spot, provided nothing deflects it from its course. This is almost like saying that it will fall to the ground in a straight line provided it does. For the prediction to hold firm *here* and *now*, the requisite provisoes are unaccountable because infinite. In practice this is paralyzing and absurd, of course, but it does manifest that the ' principle of causality ' cannot be verified in a universally valid way.

At any rate, the difference between the analytical rigour of mathematics and the unaccountable infinity of physical circumstances is not very difficult to see. Heisenberg's recourse to Aristotle's *potentia* — though this he applies in an entirely new context — could appear revolutionary only because of an unwarranted extrapolation of Newtonian mechanics to the universe as a whole. Newton himself never made this extrapolation. As Max Born emphasizes, it is too obviously contrary to everyday experience : in effect it would reduce us to helpless cogs in a vast machine.

Let us turn to another contemporary physicist who has examined the question of indeterminism in some detail, and who does not believe that the Copenhagen interpretation ought to be taken as definitive. David Bohm lays down the general principle that we must continue to probe, criticize and test every feature of every theory, no matter how fundamental that theory may seem to be. Which does not imply that the validity of our *potentia simul contradictionis* is to be temporary only, or provisional. On the contrary, he has, perhaps more than any other physicist writing about his science and about contemporary physical theory, brought out the important role of contingency in nature.

Bohm explains what he means by ' contingency ' at considerable length in his *Causality and Chance in Modern Physics*. It is noteworthy that in doing so he should first deal, as Aristotle had, with the extreme kind of ' contingency ' found in human affairs ; I refer to section 8 of chapter I. For his first instance of contingency is chance, in the sense of a purely accidental cause relative to man, which he chooses to explain by considering a " typical chance event," namely a particular automobile accident, where the slightest of an unlimited number of factors " might have prevented the accident altogether or might have changed its character completely, either for the better or for the worse."

We see, then [he goes on to say], that relative to a context in which we consider, for example, the actions and precautions that can be taken

1. A fruitful tautology, of course.

by a particular motorist, each accident has an aspect that is fortuitous. By this we mean that what happens is contingent on what are, to a high degree of approximation, independent factors, existing outside the context in question, which have no essential relationship to the characteristic traits that define just what sort of a person this motorist is and how he will behave in a given situation. For this reason, we say that relative to such a context a particular collision is not a necessary or inevitable development, but rather that it is an accident and comes about by chance, from which it also follows that, within this context, the question of just where, when, and how such a collision will take place, as well as that of whether it will take place or not, is unpredictable.

However, as the number of accidents under consideration increases, their *ensemble* acquires a new character, statistical regularities begin to appear. While the individual accidents remain unpredictable, the fact that an approximate number of them should occur over a long week-end or in the course of a year, becomes likely and, accordingly, predictable up to a point. Does this imply that where large numbers come into play, our simultaneous possibility of contradictories tends to be cancelled out? Unless I misunderstand him, Bohm maintains that the individual accident is still truly contingent to the person to whom it happens, " for better or for worse."

But why can an accident of the type described take place ? If the individual driver had everything under control, that is, all the other drivers and himself as well, together with all possible circumstances, he should then be quite safe from any accident of that type. But no driver has such control, and obviously none could have. To be sure, the inexperienced driver is in some circumstances a more likely victim than the experienced one ; but none is at all secure against every accident, whatever his experience and skill.

Like Aristotle, Bohm is concerned initially with the fortuitous, that is with chance in human actions. Aristotle had observed that we are exposed to fortune, good or bad, because our knowledge of the circumstances amidst which we act is limited. It is therefore only natural that there be fortuitous events. The root of fortune is ignorance and the inevitable limitations due to it in our practical actions. Consequently, the relative frequency of individually unpredictable events will be nothing but a function of our never quite determinate knowledge in the practical order. The fact that our ignorance and the attendant lack of control could never be wholly removed provides in the end the very basis of a measure of predictability. Our ignorance in our actions is just as much a constant as our knowledge is ; little wonder that the effects of these correlative constants should acquire a numerical value. That is why, conversely, the approximate number of predictable accidents over a long week-end in this country, say, does not at all suppress indetermination on the part of whoever incurs the accident. Insurance companies thrive upon

constants of inconstancy. That there be non-necessary events is necessary ; but that does not make any one of these particular events become necessary.

It is evident, then, that in using the word ' chance ' apropos of an individual accident and in retaining thereafter the same word to signify ' laws of chance,' we have, perhaps unwittingly, added a new meaning to that word. There is excellent reason to retain the same name in this way, but we must remain aware that its meanings are distinct.[1]

I have dwelt a little on Bohm's approach to the question of contingency in nature, for it is best in point of philosophical method to analyze first as he does the meaning of the kind of chance with which we are familiar, and then to move on to the less familiar meaning of chance as applied to nature outside human affairs — outside the realm of deliberate activity. The transition is not an easy one.

Plainly, we, in our dealings, act for a purpose ; if nature, too, acts for a purpose there will be, to that extent, a certain proportion between human action and naturel. Now we do easily see that those animals which are familiar to us seek pleasure and avoid pain. The animal trapped in a forest fire may well be said to have been the victim of chance. Similarly, to quote an example I have given elsewhere, chance can be recognized in the case of the lioness which, having lost her cubs during an elephant raid, finally gives up the search when she loses their scent at a stream ; then appears an antilope which she pursues for the sake of food ; the prey leaps across the stream, and the lioness in pursuit is suddenly faced with her cubs. Since her happy discovery was not intended in this pursuit, and yet is a good, it is a chance event in nature.

But if we confine ourselves to the so-called inanimate world and consider it in abstraction from any kind of life, especially from animal life, it is practically impossible for us to recognize concretely what is good in it, so that we could not then speak of chance in the senses mentioned up to now. If, further, we confine ourselves to the viewpoint of mathematical physics, we will, insofar as it is mathematical, perforce abstract from anything whatever which can be called good, and will not, once again, be able to speak of chance without lending the word still a new meaning. The question then is whether this new meaning will be understandable without reference to the previous ones. It could be related to the first meaning of chance in respect of unpredictability, but if the unpredictability is due only to our ignorance, we are again faced with the so-called ' principle of causality.' The principle is one which, even if it held good in nature, and unrestrictedly

1. For ' chance,' the French use *hasard* (not always the same as the English ' hazard '), from the Arab *al-zhar*, the die ; hence a game of chance played with dice. If this was the original meaning of the word, then, to signify chance in an individual accident, a new meaning was implied, and French speakers arrived at our two meanings in the reverse order.

so, we could never verify. But the question now is, can natural phenomena, as dealt with in mathematical physics, be sufficiently accounted for without the *a priori* necessity of that principle? If so, we imply that there is a measure of indetermination in nature but such that it is compatible with vast regularities sufficient to warrant predictability and so justify our science.

We must insist, however, that the indeterminacy in question is quite foreign to pure mathematics. Now this may appear strange, seeing that the calculus of probability is purely mathematical, and probability we distinguish from certainty. Yet the paradox disappears when we realize that the calculus is not probable in itself, but only in application to something extrinsic to it. And so we attribute the indetermination to nature and accordingly to mathematical physics only qua physical.

In contemporary literature chance is often equated with randomness. I see no objection to this, provided it be made plain that here is once again another meaning of chance. For there is a proportion between the indetermination of the unpredictable individual exception and the indetermination involved in random scrambling. To use Bohm's example, " when sand and cement are mixed, one does not carefully distribute each individual grain of sand and cement so as to obtain a uniform mixture, but rather one stirs the sand and cement together and depends on chance to produce a uniform mixture." The trouble with this example is, you might say, that it is *we* who do the mixing. But Bohm offers this case only as an example, not as a sample of random mixing found in nature. The point is, if regularity can be produced by our random scrambling, could not the same occur in nature ?

How careful we must be in using the word " chance " should be plain from the example just quoted. If by chance we meant randomness, to say that the random distribution of cement and sand is a product of chance would be true.[1] Chance so taken is not the exception but the rule. On the other hand, to say that the homogeneous mixture was normally produced not according to law but by mere chance, would be false.

* * *

Now a final observation : the chief difficulty we have in recognizing indeterminacy in mathematical physics appears due to the

1. The same could be said of nature's intelligible device in the production of mushrooms and men. The random distribution of millions of spores makes likely the survival of the species in a few individual mushrooms ; we too scatter random shot at a duck to compensate for the uncertainty of our aim. The duck take no comfort from our ignorance of which particular pellet will bring it down. Calculated waste may be the only means to overcome the uncertainty of survival. Einstein was right : God does not play at dice ; but He makes agents that apply the laws of chance.

fact that we abstract part from whole and then try to understand the whole solely in terms of its parts and of the laws which govern these in abstraction from the whole. Let me return to an earlier example. The fact that I can stand or not stand, while it depends upon my elemental components, cannot be explained by these alone in abstraction from myself. Whatever the laws that govern them, these laws must be such that I can stand or not stand. For I have *my* constituents ; they are involved in *my* physical comportment, which requires a degree of looseness on the part of my ultimate physical components — whatever these may be — a looseness incompatible with pure mechanism.

Assuming there is no difference between my ultimate constituents and those of a stone, all subject to general laws, these laws, if they are to be truly universal, must allow for the difference between a rock sliding down Eddington's grassy hillside, and the elephant, or the man, who may struggle against the downward slide. In other words, the universality of these laws will depend upon the different ways in which they apply ; they must allow for diverse possibilities.

To know in a general way that there must be an indeterminacy on the part of the basic constituents of natural things, one does not have to commit oneself to any given physical theory that appears to bear it out.[1] It is enough for me to know that I can rise and stand, or walk up a staircase ; which is contrary to falling into a chair or toppling down a flight of stairs. Gravitation plainly allows for this contrariety ; it allows for a simultaneous potency of opposites at the level of the ultimate constituents. Whether this indeterminacy can be indentified with the one that appears in present quantum theory or whether it is to be sought at a deeper level still, is a matter in debate. Meantime we can be certain that at some level there must be indeterminacy, since I can stand and not stand.

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1. Still, the view of the late Arthur Eddington and of Pasqual Jordan on this subject should not be summarily dismissed. Neither of them means that if Heisenberg's uncertainty relations turned out to be wholly subjective we would have to surrender the exercise of free will in the physical world.