The Metaphysical Reach of Science

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My subject today will be the positivist theory of science judged on the evidence of a historical controversy, fought out at the very dawn of science over the system of Copernicus.

Rumours of his theory that the earth moves round the sun, had been current since 1515, twenty eight years before he published it in De Revolutionibus Orbium Celestium just before his death in 1543. Two years before this, in 1541, he received a letter from a Lutheran minister in Nuremberg, named Andreas Osiander, urging him not to regard his theory as true, but merely as a hypothesis, suitable to serve as a foundation for calculations. And when the book came out, it was prefaced by an Advice to the Reader, generally attributed to Osiander, in which he elaborated his warnings. He wrote that astronomy cannot arrive at the truth for it ignores the causes of stellar motion; it should only propose hypotheses in accordance with observations and these hypotheses need not be true nor even probable.

This view coincides substantially with the positivist theory of Ernst Mach, which regards science as a convenient functional relation between observed data. This theory purports to exclude all metaphysical claims of science by restricting it to the formulation of functional relations between observed data. We shall see that this intention was also present, though with an altogether different motive, in the intervention of Osiander.

To this intervention Copernicus replied in the First Book of his volume by claiming that his system was true for it had symmetries and harmonies exclusively its own.

> The orders and magnitudes of all stars and spheres. . . become so bound together that nothing in any part thereof could be moved from its place without producing confusion in all other parts, and of the universe as a whole.

This refers to the way major epicycles of Ptolemy are replaced by a pattern of suitably spaced circular orbits centering on the sun.

The planet is observed at different points moving eastwards against the firmament of fixed stars. But not steadily. It speeds up, slows down, retraces its step and resumes this oscillation at regular intervals. This is explained by placing it on a circular orbit with a wheel attached to it: the epicycle.

Copernicus shows that the same complex motion can be explained by placing earth on a circular orbit round the sun and the other planet on another orbit round which it moves faster or slower than the earth. The planet, observed from the earth, will then be seen to pursue the same kind of periodically oscillating circular trajectory, as was described before in terms of the epicyclical mechanism (used by Ptolemy). But this does not suffice. In order to eliminate the epicycle, we must ascribe one particular orbital distance to the planet (as measured in the earth's distance from the sun). So that, in the end, we shall have fixed the solar distances of all five planets in terms of the earth's solar distance. This was the triumph of Copernicus: the internal coherence of his system. It was enhanced further by the harmonious sequence of orbital periods now apparent for all six planets, the earth being placed among them. (See table).

Osiander had attacked the claims of Copernicus on the grounds that science could no more than save the phenomena by a suitable hypothesis, which need not be true, nor even probable. This attack was continued later against the Copernicans. Galileo was attacked on these grounds and put on trial by Pope Urban the VIIIth. On behalf of the Roman church, Cardinal Bellarmine pressed him to acknowledge that the heliocentric system was but a computing device, but Galileo resisted this. I have said that Osiander's attack on the views of Copernicus coincides with the positivist view that a scientific theory is but a convenient description of observed facts. The coincidence of these two historically remote positions was borne out earlier in this century by a leading positivist writer, Paul Duhem, who declared that it was Cardinal Bellarmine and Osiander and not Galileo and Kepler who had grasped the precise significance of the experimental method. Henri Poincaré too condemned the "residual metaphysics" to which Galileo was adhering.

But the grounds on which the clergy attacked Copernicanism were quite different from those on which the positivists objected to it. The clergy defended the medieval view, formulated by Aquinas, that empirical astronomy cannot speak of metaphysical reality. It defended the privilege of philosophic reason to speak of reality against encroachment by science. The positivists rejected, on the contrary, any metaphysical statements as empty and confusing, and aimed at purifying science from any such claims. They demanded that science should refrain from claiming to be true or to be bearing on reality.

The position of the two different attacks on Copernicanism can be illustrated by a diagram. The <u>medieval</u> position shows reason bearing metaphysically on reality, while barring science from such bearing. The <u>positivist</u> position is shown isolating science both from reason and reality, <u>self contained</u> in strict empiricism. <u>Copernicanism</u> is shown, thirdly, claiming to exercise reason through science with a bearing on reality.

DIAGRAMS

In this three cornered dispute I shall side with the Copernicans; I agree with the positivists in pointing out that the Copernicans were making metaphysical claims, but I side against them by agreeing with the medievalists, that such claims are not empty but, on the contrary, essential to all true knowledge. Seen in this light, the medievalists were right, in recognising empirical science as encroaching on their domain, but wrong in contesting that science was competent to do so. The Copernicans were right in every respect.

The difficulty in meeting the positivist criticism of Copernicanism lies in the fact that there is such an obvious answer to it, namely, that the Copernicans were right, because the earth does in fact go round the sun. But, of course, Duhem and Poincare could not have overlooked this fact. They must have meant that Kepler and Galileo were wrong, and Copernicus himself even more wrong, in asserting this fact on the grounds of evidence which could be represented also by an earth centered system.

To this we may object that Kepler and Galileo--though not Copernicus--had one strong reason for asserting the reality of the heliocentric system. They may have felt that it must be real, since it was by relying on the Copernican system to be real, that they had made their own great discoveries.

But we must ask whether any such feeling could possibly be justified. If we are to accept the connection to be other than accidental, we must see clearly how the Copernican system could exercise such heuristic powers, which the Ptolemaic system would lack.

The first point to note in this connection is that Copernicus and his followers clearly felt a deficiency in their system which they tried to remedy. They felt that there must be some good reason for the central position of the sun with the planets going round it. Copernicus argued that the sun as giver of all light must be the center of the Universe. Kepler insisted on the natural pre-eminence of the sun and came near the truth by assuming that the sun emits a motive spirit (anima motrix) which keeps the planets going round. Thus the problem was kept open and alive until Newton solved it by the discovery of general gravitation.

This shows how Copernicus and his followers were guided by the heliocentric system to their enquiries. They pursued the problems suggested by a Copernican layout of the Universe. Kepler's Third Law, relating the square of planetary periods inversely to the cube of planetary distances from the sun, also elaborated a problem set by Copernicus, by observing how orbital periods steadily increase with the planet's distance from the sun. The First and Second Laws introducing the elliptic paths, with the sun in one focus of them, could hardly have been conceived by anyone who ignored the heliocentric system; for it made no sense in the Ptolemaic system. And it was of course Kepler's laws, combined with findings of Galileo, that set Newton his task and prepared his triumph.

We can take it as a fact then that the Copernican system did indicate good problems which were not visible in the Ptolemaic system. Let us now try to identify the process by which Copernicanism suggested such good problems.

This brings up an awkward question, which to my knowledge, has never been systematically examined. The question is, What is a problem? Not the kind of problem set to students of mathematics or to chemists in practical classes but a scientific problem the solution of which is unknown; the kind of problem a scientist embarks on with a reasonable hope to discover something new that will be worth the labour and expenses of the search for it.

I would answer that to have such a problem, a good problem, is to surmise the presence of something hidden, and yet possibly accessible, lying in a certain direction. A good problem--let me repeat--is a surmise of something hidden yet accessible by an enquiry in a certain direction. Such a surmise is evoked in the imagination of a scientist by a set of circumstances which come to be seen as clues to a hidden thing. When the problem is solved, these clues will seem to form part of the hidden thing that is now discovered. The clues of a problem thus anticipate parts or aspects of a future discovery.

The heliocentric system of Copernicus could raise a problem to be answered by the discovery of general gravitation because it was itself an aspect of the theory of general gravitation; and the same is true of Kepler's discoveries which lay on the way to Newton's work. Copernicus anticipated important aspects of Kepler's three laws.

The anticipations contained in the heliocentric theory are sharply distinct from its explicit predictions. The celestial timetable set out by Copernicus was not markedly different from that of Ptolemy. Close on to a century and a half following the death of Copernicus all efforts to discriminate between the two systems on the grounds of their observable quantitative predictions have failed. While the discoveries of Kepler and Galileo based on the heliocentric system greatly increased its plausibility, a medieval thinker like Belarmine and such distinguished scientists of our own days, as Duhem and Poincare, from a positivist point of view, could still regard the factual content of the two rival system as having been identical. And they were right.

Faced with this fact we may ask once more, How can one of two systems having the same predictive content, so vastly exceed the other in its anticipations? The answer is given already in what I have just described in detail. The anticipatory powers of the Copernican system lay in the new image by which it represented the predictive content of the Ptolemaic system. It is in the appearance of the new system that lay its immense superiority; it is this image that originated the Copernican revolution.

I am drawing here a distinction which will prove decisive. I distinguish between the precise predictive content of a mathematical theory consisting in a functional relation of measured variables and a meaning of the theory which goes beyond this. While these functional relations remain the same, whatever symbols are used for presenting them, the surplus of meaning which goes beyond this depends on the appearance of the theory.

The way this may come about can be illustrated from everyday life. Suppose we have a list of all the towns of England, each with its precise longitude and latitude, and the number of its inhabitants, and we represent these data in a map, each town being marked by a circle corresponding to it in size. The mapping of the list adds no new data to it, yet it conveys a far better understanding of these data. It reveals for example the way the population is distributed through the country and suggests questions about the reasons of physical geography and history which will account for this distribution. The map will guide the imagination to enter on fruitful enquiries to which the original list would leave us blind.

We can, in fact, give a fairly close analogy between the Ptolemaic and the Copernican system in such terms. Suppose you are interested only in a certain number of itineraries. They could be conveniently represented separately on several lines. You sometimes find this kind of indication in guide books. But the traveller may use instead a map on which he can trace the itineraries for himself. The first representation corresponds to the Ptolemaic, the second to the Copernican system. It is clear that the latter, though not more convenient for the original purpose, is far richer in possible implications beyond this purpose.

Returning then to the context of my argument, I shall nail down as my first result to have established and clearly identified a surplus of meaning contained in a scientific theory beyond its explicit predictions. This non explicit surplus consists in the anticipatory powers of the theory which it exercises by its general outline and appearance. This appearance appeals to the imagination of future minds and invites them to explore its possible wider implications. It suggests problems to them that lead to future discoveries. Since a precise positivist interpretation of a scientific theory insists on limiting its content to its explicit observational predictions (this being indeed the very essence of the positivist idea) it necessarily ignores its anticipatory powers and reduces it thus to sterility.

But before going further, I must yet enter a caveat. The distinction between explicit content and informal heuristic powers is profound, but not absolute. No mathematical formula means anything except as understood by him who applies it, and such an act of understanding and applying is necessarily informal. When I speak of the explicit content of a theory, I mean such applications of it which, though informal, are quite obvious. These I distinguish from the yet indeterminate meaning of the theory that may be revealed only much later, by a creative act of a scientist's imagination.

But I have still to show, if I am to justify Copernicus, that in expressing his belief in the reality of the heliocentric system, as distinct from the Ptolemaean, he was in fact asserting the presence of its anticipatory powers. This is far from obvious, since, for one thing, it is not clear how anticipatory powers can be known at all. It is clear that they cannot be explicitly known. Copernicus certainly did not know that his system represented an aspect of Kepler's laws and of Newton's theory of general gravitation. Indeed, being wedded to an explanation of the planetary system in terms of steady circular motions, he would have absolutely rejected Kepler's Laws and Newton's theory based on them.

Yet, in my view, he did show that he had this knowledge and expressed it by his affirmation that his system was real. For he based this claim on the very features of the system which were to serve as clues to the problems of Kepler and Newton and lead to their discoveries. He gloried in the internal coherence of his system and felt particularly gratified by the regular increase of orbital periods with the increasing distance of the planets from the sun. He said that this orderliness was reasonable and claimed that it was a unique quality of his system. He also tried to show that it was reasonable that the sun, as the sole provider of light to the universe, should be situated at its center. What he meant by asserting that the heliocentric system was real, must have included an anticipation of the fact that these features of his system, and perhaps others too, might yet serve as clues to future problems and that such problems may lead to yet unthinkable further discoveries.

We shall see more clearly what Copernicus meant, if we align him with his successors to whose purposes the reality of his system was even more essential than it was to him. The results of Copernicus would have remained valid and interesting, even if Osiander had been right in calling his theory a mere computing device. The followers of Copernicus were much more deeply committed. The enquiries on which Kepler spent his life, would have been altogether non-sensical, if the heliocentric system were not real. He elaborated the distinctive image of the Copernican system, basing himself on the belief that it represented a fact. Galileo was of course equally involved. The hostility and danger which he faced, added to the risks of his commitment, but a scientist pursuing a solitary problem for years is hazarding his existence as a scientist and this hazard is fearful enough by itself. The belief of Copernicus in the reality of his system thus acquired an overwhelming practical meaning for Kepler and Galileo in the form of their conviction that the problems suggested by the heliocentric image were good problems, pointing to important hidden truths.

The manifest continuity between Copernicus's belief in the reality of his system and the heuristic commitment of his followers leads me to conclude that their commitment was but an intensification of Copernicus's belief. It demonstrates that his belief in the reality of his system expressed the same kind of expectation which his followers expressed in embarking on their problems. The difference was mainly that his belief in the reality of his system was less dynamic and less pointed, than their belief in the soundness of their problems. Belief in the reality of a theory entails the expectation that any of its statements or aspects may become a clue to new problems and discoveries. Then, when this expectation materialises and new problems are discovered on these lines, these will entail more definite expectations of a hidden truth lying in a particular direction, and this expectation will lead to action in quest of the hidden truth. We may say that in rejecting Osiander's view that his theory was merely a new computing device, Copernicus <u>vaguely</u> anticipated the kind of <u>concrete</u> anticipations, called problems, which he evoked in Kepler, Galileo, and Newton.

We can generalise this result. What Copernicus meant by attributing reality to his system, is but an instance of what is commonly meant by saying that something is real and no mere figment of the mind. When we say that an object is real, we mean that it will not dissolve like a dream, but that, for better or worse, it will yet manifest its existence, inexhaustibly. We feel that it is there, outside, whether we believe it or not, existing independently of us, and hence never fully predictable in its consequences.

I propose to define reality and truth, accordingly, as follows. If anything is believed to be capable of a largely indeterminate range of future manifestations it is thus believed to be real. A statement about nature is believed to be true if it is believed to disclose an aspect of something real in nature. A true physical theory is, therefore, no mere functional relation between pointer readings, but represents an aspect of a reality, which may yet manifest itself inexhaustibly in the future.

I agree therefore with positivism in the view that if a scientific theory could be reduced to a bare functional relation between observable facts, it would have no bearing on reality nor claim to be true; but I deny that such a functional relation can constitute a scientific theory.

The difference between the scope of a statement that is only explicitly grounded and one that is claimed to be true, is shown in the deductive sciences. According to Godel's famous theorem, a sentence which says of itself that it is not demonstrable merely reflects on its origins, while a sentence which says of itself that it is not true, can be shown to be self-contradictory. The reason is that by contrast to explicit demonstration, the establishment of truth entails an unlimited commitment.

But we have still to show the ultimate grounds on which such unlimited commitments are entered upon. We may still ask why the internal harmony of the heliocentric system made Copernicus and his followers believe that it was real. The clue to the answer, and indeed most of the answer itself, may be found in the fact that the existence of a harmonious order is a denial of randomness. Something that is random is meaningless, and, by contrast, anything that is orderly, is meaningful.

Take the difference between a tune and a noise. Or, more generally, between a message and a noise. Communication theory defines a noise, by contrast to any distinctive series of signals, as a random sequence and says that, as such, noise conveys no information, means nothing. This shows that order is strictly complementary to randomness; each starts where the other ends and each can be conceived only as the denial of the other. There is a very important difference in the identifiability of an ordered sequence as compared with a noise. Any single message is represented ideally by only one configuration of signals, while for a noise the very opposite holds. No significance must be attached to any particular configuration of signals that are a mere noise. We must indiscriminately identify any particular configuration of a noise, with any other configuration of them. And this is true of any random aggregate: the chance events which compose it could have as well happened otherwise. By contrast, once we have recognised an aggregate as orderly and meaningful, we cannot think that it might just as well have happened differently. It is deemed an identifiable thing, possessing reality in the sense I have defined it, namely that, being real, it may yet manifest itself inexhaustibly in the future. To distinguish meaningful patterns from random aggregates is therefore rightly described as the power for structuring reality.

Our capacity for discerning meaningful aggregates as distinct from chance aggregates is an ultimate power of personal judgment. It can be aided by explicit argument but never determined by it.

The final decision will always remain tacit. Such a distinction may of course be so obvious, that our tacit powers are used effortlessly and their use remains unnoticed. Our eyes and ears make such decisions almost automatically for us. But decisions of this kind may be hard and momentous. A jury may be presented with a pattern of circumstantial evidence pointing to the accused. It is always conceivable that this pattern may be due to chance. Just how unlikely a chance should they admit as possible? What degree of coincidence should be deemed to be quite unbelievable? The prisoner's life will depend on the decision, and there is no rule by which this can be decided.

Admittedly, rules for setting a limit to the improbability of chances which a scientist might properly assume to have occurred have been widely accepted among scientists. But these rules have no other foundation than a vague feeling for what a scientist may regard as an unreasonable chance. The late Enrico Fermi is reported to have said that a miracle is an event the chances of which are less than one in ten. The rule which R. A. Fisher in his book, The Design of Experiments, has made widely current is a little more cautious; it rejects as illusory only patterns for which the odds of having been formed by chance is less than one in twenty. But if anyone were to suggest that the limit should be set at one in five or at one in two hundred, nothing more could be said against this than that it does not seem reasonable.

Such decisions will also greatly depend on the kind of connections we deem plausible on general grounds. We shall accept much less substantial evidence for plausible patterns or regularities than we would require for connections which we consider highly improbable. Kepler has put forward along with his three laws, and just as triumphantly, other regularities in the Solar system which we brush aside today, for we no longer believe that that kind of connection could be real. A curious numerical law governing the spacing of the planets, usually described as Bode's Law, has been known for about two centuries. Long since discredited, it was recently given currency once more by C. F. von Weizsacker, for he thought he had an explanation for it. A very substantial body of evidence which I produced about 50 years for my theory of the adsorption of gases on solids, was brushed aside soon after its publication, because the theory which this evidence supported was found incompatible with the electrical structure of matter as discovered by Bohr, Debye and the Braggs. Later when Fritz London, late of this university, revised this view of molecular forces on the grounds of the new quantum mechanics, the evidence became once more acceptable, while other experimental evidence--put forward by no less a man than Irving Langmuir--which had supported the previously held view concerning molecular forces, now turned out to be erroneous. I have reported this story in the September 13th issue of Science, published in Washington.

I have said that reality in nature was something that persists outside and may yet manifest itself inexhaustibly, far beyond our present ken. Something must be added to this description, if the pursuit of natural science is to be justified. Consider that the Copernican revolution was but a continuation of a structuring that had its origins in antiquity. Copernicus deepened and beautifully clarified a coherence transmitted by Ptolemy. And this triumph pointed beyond itself in the mind of Copernicus himself. In Kepler, passionately embracing the system of Copernicus, its image evoked anew the same kind of creative hunger which Copernicus had satisfied by discovering it. And still the presence of yet hidden truth worked its way ever further. To Newton, Kepler's laws appeared incoherent and he responded by developing the theory of general gravitation in which Kepler's three laws were jointly derived from the mechanics of Galileo. Nor was this the end, for a quarter of a millennium later, Einstein was to find unsatisfying the relation of the Newtonian system to the electromagnetic theory of light and to discover an even deeper coherence to reconcile the two.

The continued pursuit of science is possible, because the structure of nature and the capacity of the human mind to grasp this structure, are frequently such as is exemplified by this sequence of discoveries during the past two thousand years. It seems frequently to be the case that nature is capable of being grasped in successive stages, each of which can be reached only by the highest powers of the human mind. Consequently, to discover a true coherence in nature is in general not only to discern something which by the mere fact of being real, necessarily points beyond itself, but to anticipate that future discoveries may prove such reality to be far deeper still than our present thought can anticipate.

It may sound strange that I insist on a belief in the reality of theoretical suppositions as the driving force to discovery. It would seem a conservative conviction rather than a source of innovation. The positivist view of science would claim that the major discoveries of modern physics were based on a sceptical attitude towards the framework of hitherto accepted scientific theories. The discovery of relativity involved the abandonment of the current conceptions of space and time and quantum mechanics achieved its breakthrough by discarding the planetary system of electrons circling the nucleus from which Niels Bohr had derived the theory of atomic spectra. Einstein himself acknowledged that Mach's positivist philosophy inspired his work and Heisenberg's quantum mechanics was deliberately framed to reduce atomic theory to a functional relation of observable quantities. It was with this in mind that one spoke of the modern epistemological method in science.

These facts seem to contradict my thesis, but I think they will fall into line with it, if I first make clearer the opposite extreme of creative procedure, based on a firm belief in the reality of the current framework of scientific theory. We may recognise the prototype of such a feat in the discovery of America by Columbus. He triumphed by taking literally, and as guide to action, that the earth was round, which his contemporaries held vaguely and as a mere matter of speculation. The egg of Columbus is the proverbial symbol for such breath-taking originality guided by a crudely concrete imagination. I remember having the same feeling when first hearing of Einstein's theory of Brownian motion. The idea that the meandering motion of small floating particles seen under the microscope, should show us the impact of molecules knocking them about in accordance with the equations by which Boltzman and Maxwell had derived the kinetic theory of gases, impressed me as grossly incongruous--like something out of science fiction. I had the same kind of feeling that I was listening to something grossly fantastic, when I heard Elsasser suggesting (in 1925) that certain anomalies observed in the scattering of electrons by solids may be due to the optical interference of their de Broglie waves. We had all heard of the waves since 1923, yet were astounded by the fact that they could be taken literally as Elsasser did.

This may remind us that the first great move towards the discovery of quantum mechanics was de Broglie's idea of the wave nature of matter. This revolutionary idea and Schrodinger's development of it into wave mechanics, shows no trace of any positivistic influences. Add to this that Max Planck, the founder of quantum theory was an active opponent of Mach's analysis of science and dissented also from Heisenberg's claim of basing physical theories on directly observable quantities. It appears then that the pre-dominant principle that shaped modern physical theory was not the positivist program but the transition from a mechanical conception of reality to a mathematical conception of it, which sometimes coincided with positivistic aims.

We can bring then the revolution of the twentieth century into line with the Copernican revolution of the 16th and 17th century. They both consisted in a decisive deepening of coherence with a simultaneous extension of its range. The modern revolution differed from its precursor in establishing mathematical harmonies in place of beautiful mechanical systems.

The mathematical image of reality is more abstract than the mechanical but its capacity to point beyond its immediate predictive content is similar to that of the mechanical image. The idea that the wave nature of particles postulated by de Broglie could be confirmed by diffraction experiments came as a fantastic surprise to physicists. The discovery of the positron came about just as unexpectedly to confirm a prediction contained unnoticed by its author in a mathematical theory of Dirac. Generally speaking, the transformation of modern physics started with the discovery of quantum theory by Planck in 1900 and continued after that by a series of attempts to restore the coherence of the image brutally broken by this discovery. Each successive step in this process was anticipated in part by its antecedents and thus testified to its bearing on reality far beyond its explicit content. It was in the course of this enterprise that mathematical beauty manifestly became a guide to discovery and was recognised as the final token of truth. Paul Dirac has repeatedly observed this fact.

My account of the Copernican revolution and of the modern revolution in physics has mentioned only in passing the contributions made by new experimental observations. But the examples I have given were typical of the way experiments during this period often followed the theoretical anticipation of them, the connection being often not recognized at first. Theoretical speculation and experimental probing entered jointly into a persistent quest towards an ever wider and deeper coherence.

This remark brings up the question, how the actual process of discovery is performed. Much has been written about this with which I disagree, but I can put my own views only quite summarily at this stage. To see a good problem is to see something hidden and yet accessible. This is done by integrating some raw experiences into clues pointing to a gap. To undertake a problem is to commit oneself to the belief that you can fill in this gap and make thereby a new contact with reality. Such a commitment must be passionate. A problem which does not worry us and the prospects of which do not excite us is not a problem; it does not exist. A problem is discerned by integrating bits of experience to a fragmentary pattern which, if completed, will touch upon reality. Completion, which solves the problem, is achieved by a sustained quest for deeper coherence. Every move towards this aim is prompted by an intense desire evoked and guided by a sense of approaching discovery.

Such is the dynamic form of the anticipatory powers seen before in a historical perspective. Without them no research can succeed; cannot even be said to take place.

Natural ability for discerning the incipient coherence of things and sensing the direction towards deeper coherence, varies to about the same extent among men as does the ability for boxing, ballet dancing or playing chess. Theories of discovery which offer no decisive role to scientific genius have no bearing on discovery. This is true also for theories in which hypotheses arise unaccountably and are entertained for no better reason than to try everything once. Nor is it true that we could select from such hypotheses those which are false by letting them be knocked out by a fact which contradicts them. Any contradictory evidence can be judged only within the context of the quest; judgment must ultimately depend on our sense of approaching coherence. In any case, ulterior refutations cannot produce a discovery.

The dynamics of discovery are brought into action by committing ourselves to certain anticipations. Without such commitment no supporting evidence will turn up; no failure to find such evidence will be felt; no conclusions will be drawn and tested; no quest will take place. Evidence can be mobilised only by a surmise, which being a vision of the truth we are after, necessarily seeks its own confirmation. Such commitment exposes us to possible failure, but to risk failure is not to aim at it. To say that in this process we are seeking the refutation of the hypothesis we are entertaining, as K. R. Popper often says, is misleading. A mountaineer may risk disaster, but he does not set out to meet with disaster.

When distinguished minds arrive at conclusions which seem quite unacceptable, we may be sure that the fault lies deeply buried in their premises. In these lectures and seminars I shall introduce a principle that is missing in these premises. I want to define and recognise the powers of the mind by which coherence is discovered in nature. This will place on solid grounds the progression of discovery, guided by anticipations of reality, of which I have spoken.

And it should do more. The triumph of coherence achieved by the Copernican Revolution filled those brought up in the Medieval tradition with dismay. The earth's central position had been the symbol of man's destiny as the only thinking, morally responsible being in the universe. The providential meaning of nature, which had confirmed man in the ordering of his life, was lost in the new, symbolically meaningless image of the universe. "It is all in pieces, all coherence gone", wrote John Donne already in 1611.

This conflict has steadily widened up to this day. The destruction of the ancient cosmic hierarchy has spread into a theoretical denial of all higher forms of existence. The ultimate components of things, including those that make up man and his thoughts were all placed on an identical level of being. Just as the harmonies of Copernicus disappear in the Newtonian equations and become mere accidental formations of them, so must all complex entities now be reduced to the law governing their components. Then, truly, all coherence is gone.

But once we credit ourselves with genuine powers of integration, the structure of our comprehension will re-appear in that which we comprehend. This will restore stratification to the universe: we shall recognise a set of logically identifiable levels of existence. In such a hierarchy man takes his place as the creature by which the universe knows itself. And so eventually, he may be able to make himself at home again in the universe.