The Philosophical Frontiers of Physics

A DISSERTATION

[illegible] OF PHILOSOPHY OF THE CATHOLIC UNIVERSITY
[illegible] PARTIAL FULFILLMENT OF THE REQUIREMENTS
[illegible] DEGREE OF DOCTOR OF PHILOSOPHY

BY
[illegible] EDWARD SMITH, M.A.

The Catholic University of America
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TO
THE MOST REV. JOHN T. McNICHOLAS, O.P., S.T.M.
ARCHBISHOP OF CINCINNATI
SCHOLAR AND PATRON OF SCHOLARSHIP
THE FOLLOWING PAGES
ARE THANKFULLY DEDICATED

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PREFACE

This dissertation, projected before the author's entry into military service, is published now, at a time when the current of science in the post-war world has given fresh, heavier charges to the problem of empirical knowledge. No longer does the scientific method (if indeed it ever did) present a mere classroom problem for specialized students who major in philosophy. The fate of man's civilization is bound up in his attitude toward science. His whole hope seems to rest in the stand he takes toward the method of science and toward the material means which the method procures. If this stand is to be firmly footed and is not to be a mere whim that might live today but leave man trembling before tomorrow, then the vast reality of science, in the value of its method and the meaning of its conclusions, must be examined in a considered, rational, certifying way. A pace along this long, rugged, complicated road of examining modern science is the purpose of the following pages.

It did not take an atom bomb, radar, or the VT fuse to awaken philosophers to the problem of empirical knowledge. There were, at the very dawn of the modern age, the intellectual atoms of Cartesian rationalism and British empiricism. These exploded so forcefully that philosophy, ever since, has been busied with the ensuing chain-reaction. Modern philosophy is very largely the philosophy of science. It has largely become the study of a method, as though method could ever be studied apart from matter. It is largely the science of the sciences, as though we could ever study knowledge apart from its object. The result has simply been the meaningless, circular rhythm of scientific method applied to scientific method. It is as though technique could ever be studied away from art, form without matter, and movement apart from a thing moved. Such approaches to the physical sciences have not been too successful. They have not been intellectually sound because of their Cartesian concept of method separate from matter. They have not been practically prosperous because they lead to intellectual skepticism, moral indifference, and emotions of fear and anxiety. For example, if we examine method apart from matter, then we must examine the method of applying the method to matter. So on and on.

The present study does not aim to criticize the so-called scientific method as an abstract thing. As far as writing space and non-mathematical language would allow, technical procedures and technical data have been sketched to exemplify scientific method, and the last two chapters are devoted wholly to the material furnished by science—devoted, namely, to the scientific method in action. The desire to present the procedures of science as materially as possible, as seen by both scientist and philosopher, has in some chapters the handicap that much of the text is expository and little comparative space left for criticism. But a more completely critical procedure would not have provided room for proper emphasis on what the scientist actually does. Whatever philosophical comments and criticisms have entered into these earlier chapters were deemed necessary to avoid misunderstanding or to answer immediate problems raised by the expository material. If the result has been in some cases a repetition, in a later and more elaborate form, of what these earlier chapters have said in part, it can only be replied that a well-rounded treatment of the various aspects of the vast subject of science must necessarily result in some overlapping.

Exposition is indeed not outside the science of philosophy. In many cases, to define and describe a thing accurately is to put it in its proper place so that further critical questions are either unnecessary or matched by self-evident answers. The common notion of our age, that direct demonstration is necessary for every truth, cuts away the beginning and end of knowledge, leaving such a purely scientific method hanging in a meaningless vacuum. Physics would simply have to cease existing if this notion were ever carried out. Happily, despite the protest of positivism, every physicist implicitly accepts something outside the scientific method, namely, self-evidence. Without it, the physicist, as a scientist and as a man, would be intellectually paralyzed. If we are told that the scientific method is validated by its fruits, then we may ask how this pragmatic norm is justified in itself. At last we are plunging once more into the bottomless, meaningless pits of the infinite regression.

One of the great milestones of our journey is passed when we get a sound idea of what the physicist is doing. So much of the literature in contemporary philosophy is the product of *a priori* philosophers, striving to deduce science, or *a priori* scientists, seeking to absorb philosophy. Prejudiced from the outset, they fail to describe what the scientist is really doing, and any estimate, on this basis, of scientific method must suffer correspondingly.

Those who are in fact or in spirit positivistic would reject much of the following pages as containing "'metaphysical presuppositions." Metaphysics, yes, but presuppositions, no! For there is a method of knowledge, outside the scientific method, in the science of philosophy which proceeds by entitative analysis of experience and which gives rise to metaphysics. In the branch of philosophy which deals with the possibility of our knowledge of being, the method of reflection is used, reflection—the self-evident, immediate fact—in which man, being the subject and object of his own actions, escapes from the infinite regression demanded by pure scientific method.

Reflection is an undeniable, self-evident fact, and its fruits, rooted in experience, are valid knowledge. By reflection, philosophy can justify its own self and its own method, whereas the mediating, discursive method of physics slopes toward a meaningless infinity. Without something definite, non-atomistic, and non-circular, the method of physics is itself a meaningless question and the product of mere presuppositions. If everything is mediate, as physics says, then there is nothing that is. Man may just as well take in the shingle of all human knowledge, because the world has done so with its being-ness, leaving only a vacuum as an object of knowledge.

The bibliography is quite selective. In the impossibility of citing the long list of books and articles on the implications of science, the bibliography has been sifted to include only works which bear substantially on the subjects treated in the text, and unless more than a single writing is cited at length or for some other equally valid reason, only one work representative of a given author or given school of thought has been mentioned.

The author is deeply grateful to the Very Rev. Dr. Ignatius Smith, O.P., dean of the School of Philosophy at Catholic University, whose kind and scholarly interest was inspiringly felt not only in the matter of critically assisting this dissertation but also in the more general questions and problems of student life. Special thanks are due to the Rev. Dr. John K. Ryan, under whose guidance this dissertation was written. Not only did he help by direct advice on the dissertation, but his weekly seminar was a valuable stimulus in many ways. To the other readers of the manuscript, a deep debt is likewise owed for their positive contribution. They are Dr. Rudolf Allers and the Rev. Dr. William J. McDonald, of the faculty of the School of Philosophy at Catholic University; the Rt. Rev. Msgr. James W. O'Brien, rector of Mt. St. Mary Seminary, Norwood, Ohio; the Rt. Rev. Msgr. Walter J. Roddy, rector of St. Gregory Seminary, Cincinnati; and my wife, Virginia Beck Smith.

CHAPTER I

Physics and Philosophy—Disputed Frontiers

I

The frontiers of physics and philosophy are a disputed territory in contemporary thought. The views on the subject are remarkable both for number and for kind. Not only do present-day philosophers, claiming the right to criticize physics, disagree as to its meaning and value; but scientists themselves have in recent years been turning out philosophies of their own making. The diverging views of contemporary writers tend to complicate more and more a problem already great enough by the mere historic fact of the separation of science and philosophy. As divorce works hardships on the children of a marriage, so the divorce of science and philosophy has left its mark not only on the thinkers of the two fields but upon the whole intellectual life of modern man.

It is in history that the problem began; only in the light of history can it be fully analyzed and answered. The Greeks, believers in the harmony of nature and in the unity of knowledge, studied the material world as a unit. Their point of view was inherited by their intellectual descendants in the medieval schools. The *Physica* of Aristotle and Aquinas employs the phenomenal world as a stepping-stone to a knowledge of its underlying substances and its ultimate causes. On the other hand, the physics of the present day seeks knowledge only of the interrelations of the phenomena themselves.[1] As Aristotle wrote: "Knowledge is the object of our inquiry, and men do not think they know a thing till they have grasped the 'why' of it (which is to grasp its primary cause)."[2]

[1] Cornford, F. M., "Greek Philosophy and Modern Science," in *Background to Modern Science,* edited by J. Needham and W. Pagel, New York, 1938, p. 12.

[2] *Phys.,* 194b, 18ff. The English translation of Aristotle here and hereafter is taken from *The Works of Aristotle,* edited by W. D. Ross, Oxford, 1930. Abbreviations in citing Aristotle and Aquinas will be recognized from standard works of each.

The scholastics by no means neglected experiment. Even Aquinas and Duns Scotus, essentially metaphysicians rather than empirical scientists in the modern sense, extol an experimental method.[3] It was not that they loved the relative less but that they loved the absolute more. They refrained from doing what has been done in our own age, viz., to exploit the experimental method as a law unto itself. Their lives and their learning were essentially theocentric.

How much modern science is indebted to the schoolmen for its positive principles of method is a question that remains to be studied in its fullness. Whitehead has summed up the case thus: "It needs but a sentence to point out how the habit of definite exact thought was implanted in the European mind by the long dominance of scholastic logic and scholastic divinity," and "the greatest contribution of medievalism to the formation of the scientific movement" was "the inexpugnable belief that every detailed occurrence can be correlated with its antecedents in a perfectly definite manner, exemplifying general principles."[4] But the debt of modern science to scholastic thought is more than the art of logic and the belief in nature's uniformity. Gilson, in a searching study of the relation of scholastic philosophy to Descartes, who was in many ways the founder of modern philosophy and modern mathematical physics, affirms: "From the beginning, Cartesian physics presented itself to us as a new ferment, working over and assimilating a host of old ideas, so much so that Cartesian metaphysics appeared as what scholasticism becomes in a world which contains only extension and motion."[5] Descartes had studied scholastic philosophy in the college at La Flêche where his courses were patterned on the great systems of the thirteenth century.

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[3] Aquinas writes: "Qui sensum negligit in naturalibus incidit in errorem." *In de Trin. Boeth.*, 6, 2. "Ut hoc modo judicemus de rebus naturalibus secundum quod sensus ea demonstrat." *Ibid.* Scotus writes: "De cognitis per experientiam dico quod licet experientia non habeatur de omnibus singularibus, sed de pluribus, nec quod semper sed quod pluries, tamen expertus infallibiliter novit quod ita est quod semper et in omnibus. . . ." *Commentory on the Sentences* I, d. 3, q. 4, n. 9.

[4] *Science and the Modern World*, New York, 1925, p. 17.

[5] Translated from *Etudes sur le Rôle de la Pensée Médiévale dans la Formation du Système Cartésien*, Paris, 1930, p. 143.

Gilson has traced five hundred and eighty-two Cartesian concepts to a scholastic origin.[6]

Francis Bacon, though not so important as Descartes but nevertheless a philosophical patron of experiment, was also influenced by the past. He condemns the syllogism because notions are "improperly and overhastily abstracted from facts, vague, not sufficiently definite, faulty, in short, in many ways,"[7] a possibility which Aristotle himself warned against in his *Topics* and sought to combat by insisting on clear definitions. Bacon therefore rejected Aristotelian logic. He proposed a new system. But his method, like Cartesianism, is not completely new. It is not without its debt to the past. Indeed, his induction by exclusion has its counterpart in the method of definition as found in Plato—a fact which Bacon himself acknowledges.[8] His three Tables—the Table of Essence and Presence, the Table of Deviation or Absence in Proximity, and the Table of Degrees or Comparison—which are designed to help the mind in its inductive process of exclusion—are all based upon a single principle that can be best stated in terms of the third Table: "it necessarily follows that no nature can be taken as the true form, unless it always decrease when the nature in question decreases, and in like manner always increase when the nature in question increases."[9] But though these tables are regarded as historical innovations and have formed the basis for Mill's canons, they have a counterpart in Aristotle who writes: ". . . if an increase of the accident follows an increase of the subject, clearly the accident belongs, while if it does not

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[6] *Index Scolastico-Cartésien*, Paris, 1912.

[7] *The Works of Francis Bacon*, ed. Spedding, Ellis, and Heath, London, 1858, vol. 4, p. 49.

[8] "But the induction which is to be available for the discovery and demonstration of the sciences and arts, must analyze nature by proper rejections and exclusions; and then after a sufficient number of negatives, come to a conclusion on the affirmative instances: which has not yet been done or even attempted, save only by Plato, who does indeed employ this form of induction to a certain extent for the purpose of discussing definitions and ideas," *ibid.*, vol. 4, pp. 97-98. But Plato's method is an intellectual analysis and hence not exactly the same as Bacon's crude method which is both theoretically unfounded and impossible in practice, as will be later apparent.

[9] *Ibid.*, vol. 4, p. 137.

follow, the accident does not belong. You should establish this by induction."[10]

It is obvious that Descartes and Francis Bacon, the philosophers of the scientific movement at its origin, did not present completely new systems. Much of the scientific movement is not a new creation. It is an evolution of ideas already present in amoebic form within the body of earlier thought.[11]

But if they were children of scholastic philosophy, Bacon and Descartes were in great measure the philosophical founders of the modern scientific movement in proposing the autonomy of science. Rejecting formal and final causes from knowledge, they opened the way for a division of labor in the study of the cosmos. Empirical science has asserted its dominion over the proximate material and motor causes of the visible world. Scholastics have insisted that the scientist's picture is incomplete. He fails to take form and finality into account.

But the philosophy of modern physics in its historical genesis is not the work only of theorists like Bacon and Descartes. It was the professed physicists and practical experimenters—Leonardo da Vinci, Galileo, Tycho Brahe, Kepler, Newton, and a host of others less renowned—who seemed, by the sheer success of their work, to evince the self-sufficiency of experiment.[12] Leonardo was using and urging experiment before Galileo and Bacon were born. Galileo and Tycho were methodical experimenters. In the work of Kepler and Newton, classical mechanics was furnished with a broad foundation. Physics had not only gained its autonomy in a theoretical sense through Cartesian metaphysics and the rising tide of English empiricism. In a practical way, it seemed able to confute the notion that form and finality are needed to explore

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[10] *Top.* 115a, 2 ff.

[11] Even the study of phenomena by the mathematical methods of modern physics is suggested by Aristotle in *An. Post.* 79a, 1 ff. and by Aquinas who writes: "Similiter autem corpus naturale addit materiam sensibilem super magnitudinem mathematicam: et ideo non est inconveniens si naturalis in demonstrationibus utatur principiis mathematiciis," *In De Coelo et Mundo*, 1, 3.

[12] Dampier, W. C. D., *A History of Science*, Cambridge, 1932, C. III and IV.

and explain the world of matter. Without recourse to traditional concepts that were not believed verifiable by direct experiment, physics was able to discover laws, to explain phenomena. If God entered into the thought of the scientist, it was only that He wound up the clock of the universe and let it run. Matter and motion became the only realities worth knowing; in terms of them, the whole universe seemed explainable, from the farthest star to the smallest atom. The tide was turning not only away from philosophy but against it. As physics continued its triumphs in mechanics, in optics, in electromagnetism, in short in all fields of experiment, it tended to be viewed as the supreme science. When the physicists themselves did not feel the influences of thinkers like Kant and Hume who glorified physics, they did not at any rate advert to the insistence of orthodox thought which made physics only a part of knowledge. If the scientists did not take a positive stand against traditional philosophy, they simply ignored it as meaningless. They focused their attention on laboratory problems. It has been the neglect of all formal philosophy, much more than the acceptance of false systems, which has led gradually to the belief in physical science as the sole valid approach to the cosmos.

Newton was influenced by the English empirical tradition, which began with Francis Bacon and had been foreshadowed by his namesake and fellow countryman, Roger Bacon. But sharing in the development of classical mechanics were the continental physico-mathematicians who, if they accepted the Newtonian system, showed clearly the influence of Descartes in their important use of deduction. The divergencies in the approach to physics, from the empirical and mathematical viewpoints, remained almost geographical until very recent times. The English physicists have, as a whole, tended to emphasize the experimental method; the continentals in general have stressed the deductive use of mathematical theories. The two tributaries, however, came together eventually in physics; they also converge through Kant in the philosophy of science. Philosophy and physics have thus tended in almost parallel fashion toward the same end in shaping the contemporary attitude toward science.

Aside from their destructive work in divorcing science and philosophy, Bacon and Descartes, each in the tradition he created, made one outstanding gift to modern science: taken together they can serve as a broad introductory definition to modern physics. Bacon contributed the method of observation and experiment. Descartes fostered the mathematization of the observed.[13] Descartes and Bacon thus complemented each other. Each is strong where the other is weak. Descartes was familiar with Bacon's works. He stated that he had nothing further to add on the subject of experiment to Bacon's work.[14] Descartes also knew and practiced induction and was, himself, an experimental scientist. It was these two general themes, that of the Baconian empirical tradition and that of Descartes, the continental mathematician, which have come together in the harmony of mathematical physics.

From the philosophical viewpoint, the two traditions enjoyed an independent development until the syncretism of Hume and Leibniz in the philosophy of Kant. Like Descartes, Kant was almost fanatically impressed with the certain character of deductive mathematical reasoning. Unlike his French forbear, he said that the *a priori* character of mathematics ruled it out as a science of the real. The result was a compromise—the synthetic *a priori* judgments, necessary in character but confined to physical experience.[15] Kant repudiated metaphysics. He enthroned physics

[13] As Descartes wrote: ". . . Mechanicae meae, hoc est Physica," *Oeuvres*, ed. Adam and Tannery, tome I, p. 524.

[14] For the relation of Bacon and Descartes, see Broad, C. D., *The Philosophy of Francis Bacon*, Cambridge, 1926, p. 64; Milhaud, G., *Descartes Savant*, Paris, 1921, pp. 213-227; Lalande, A., "Sur Quelques Textes de Bacon et Descartes," *Revue de Métaphysique et Morale*, vol. 19, pp. 296-311.

[15] "Naturwissenschaft (Physica) enthält synthetische Urteile a priori als Prinzipien in sich. Ich will nur ein Paar Sätze zum Beispeil anführen, als den Satz dass in allen Veränderungen der körperlichen Welt die Quantität der Materie unverändert bleibe, oder, dass in aller Mitteilungen der Bewegung Wirkung und Gegenwirkung jederzeit einander gleich sein müssen. An beiden ist nicht allein die Notwendigkeit mithin ihr Ursprung a priori, sondern such dass sie synthetische Sätze sind, klar. Denn in dem Begriffe der Materie denke ich mir nicht die Beharrlichkeit, sondern bloss ihre Gegenwart im Raume durch die Erfüllung desselben. Also gehe ich wirklich über den Begriff von der Materie hinaus, um etwas a priori zu ihm hinzudenken, wass ich in ihm dachte. Der Satz ist also nicht analytisch, sondern synthetisch und dennoch a priori gedacht, und so in der übrigen Sätzen des reinen Teils der Naturwissenschaft," *Immanuel Kants Werke*, Berlin, 1913, vol. 3, pp. 4-5.

as the ultimate human knowledge of the real. He sought to fix the foundations of Newtonian physics through the doctrine of the *a priori* categories.

Like Bacon, Kant had only an indirect influence on the development of physics. His influence was exerted in the nineteenth century much more through the positivism to which his attack on metaphysics gave impetus and through the general spirit of criticism which he provoked in men like Mach and Poincaré. In positivism is found the ultimate fate of the modern philosophy of science—the elevation of empirical method into the only valid means of knowing. It is this system of thought in one form or another which has permeated the outlook of the modern scientist, the modern philosopher, indeed of the modern intellectual as a whole.

It was actually with the downfall of Newtonian physics that the name of Kant has come to the fore in scientific circles. Scientists themselves have become self-critical. Though their epistemological conclusions are largely the result of independent thinking, they have a remarkable affinity to those of Kant. "We do not accept the Kantian label," Eddington writes, "but as a matter of acknowledgement, it is right to say that Kant anticipated to a remarkable extent the ideas to which we are now being impelled by the modern development of physics."[16] The ideas to which Eddington refers are simply that, even in matters of measurement, contemporary physics finds itself unable to resolve experience into rigid categories of thought. The principle of indeterminism, the failure of nineteenth-century atom "models," and the general revolt against classical physics in the quantum and relativity theories have led to the belief that the mind imposes mathematical frames upon reality after the manner of Kant's *a priori* forms. Hence, there are in reality two broad contemporary attitudes toward science, positivism and idealism, both of which have been abetted by Kant's critique of knowledge and in a more remote way by the empiricist and Cartesian traditions to which

[16] *The Philosophy of Physical Science*, Cambridge, 1939, p. 189; cf. also Haldane, J. B. S., *Possible Worlds*, London, 1927, pp. 124-9.

they owe their ultimate origins. In the last analysis, both positivism and Idealism meet the same fate. This fate is skepticism.

It must be affirmed that the current philosophy of science is not a mere classroom problem, not an accidental historical circumstance that arose suddenly and without reason. Its roots reach deep into the past. History sheds added light on its nature. The problem cannot be solved without recourse to the past. Nor can we understand even what it is and why it is important if we look only to the present. The history of philosophy of science follows a course subject to a rational interpretation which helps to understand and answer the problems raised. Above all, the historical genesis of the contemporary attitudes toward physics can indicate the complexity of the problem; it tempers the natural confidence of the *philosophia perennis* by locating its present work in proper temporal perspective.

II

The philosophical views of modern scientists and modern philosophers of science are almost invariably based upon the faith in the universal validity of scientific method. But an integral knowledge of nature cannot be so attained. If physics is incomplete because of the rejection of the real character of form and finality, an integral study of nature will be made only when these two realities are recovered. The recourse to systems of a Kantian theme will only make philosophy a type of glorified physics by elevating a part of the study of the cosmos into the whole treatment and by thus continuing in sublimated form the short-comings of Descartes and of English empiricism.

When the synthesis of the schoolmen had been supplanted by the so-called inductive sciences, it became the task of genuine philosophy, looking at the new disciplines from the outside and no longer as a part of its organic self, to evaluate the principles, methods, and conclusions of the sciences with only a general knowledge of their nature. The traditional philosophy has met this challenge in several ways; it has made distinctions: a) between the descriptive method of the physicist and the explanatory method of the philosopher; b) between mensuration and ontological interpretation; c) between induction and deduction; d) between substance, the subject-matter of philosophy, and accidents or phenomena, the subject-matter of the empirical sciences; d) between scientific facts and philosophical facts. But none of these has been entirely successful in restoring the proper order of knowledge.

Among the reasons for this lack of success are the unity of man and of matter:

First of all, man is a unified being. He does not stop to remind himself that he is now thinking as a scientist, now as a philosopher, when confronted with a given concrete problem. He is both a scientist and a philosopher in one composite. Though he may recognize in theory the distinction between the two disciplines, in practice he will ineluctably project his metaphysics as a man into the facts he observes as a scientist.[17] The inductive scientist, as the physicist is sometimes called, is today tending to become more and more deductive. Deduction and induction are, of course, interlaced in the traditional logic. Though deduction is sometimes made synonymous with the method of the syllogism, it is by induction that we come to know the principles of demonstration and the intelligible essences which form its material basis. A similar "mixed method" is in vogue among scientists. "Science is deductive as well as inductive," says Ritchie. "Induction we have always with us, but it is by itself a method of discovery only. Proof is something different."[18] Many problems are, therefore, raised by the attempt to divide science and philosophy on the basis of method. In practice, the scientist both as a scientist and as a man will not observe the distinction.[19]

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[17] "L'homme fait de la métaphysique comme il respire sans le vouloir et surtout sans s'en douter la plupart de temps," Meyerson, E., *De l'Explication dans les Sciences,* Paris, 1927, p. 20.

[18] Ritchie, A. D., *Scientific Method,* New York, 1923, p. 1.

[19] Schroedinger has well expressed the scientist's point of view in this matter: "Following Kirchoff we have been accustomed to admit that science is ultimately concerned with nothing else than a precise and conscientious description of what has been perceived through the sense. The dictum of this eminent theorist has often been quoted as a prudent warning to all those who engage in the construction of theories. From the epistemological point of view, it undoubtedly contains a good deal of truth; but it is not in accord with the psychology of research," *Science and the Human Temperament,* New York, 1935, p. 93.

The same problem is met in dividing off subject-matter. There is a distinction only between substance and accidents. There is no separation. In view of their unity in nature the scientist will naturally tend to philosophize about the substrata of the phenomena which do, after all, introduce us to an indirect cognition of substance.[20] Hence, the distinction between science and philosophy is again not rigidly observed in practice. Duhem was right in pointing out that there is more certitude in the popular mind than in science *qua* science since there is a deeper ontology in the former case than in the study of mutable contingent accidents alone.[21] Empirical knowledge in its pure form is not humanly practical. The scientist is not only a scientist. He is a man. The human mind will ask and answer in some way questions concerning the ultimate nature of the material world.

This does not mean that it has been false and fruitless to make these distinctions. They do exist. They must be recognized in a speculative sense. In a practical way they have done much to clear up the confusion and conflict prevailing between science and philosophy since they parted ways at the close of the middle ages. It will be found necessary to make such distinctions in the following pages. But a complete peace will not be re-established on a practical plane until the two branches are reunited in organic harmony on the common tree of knowledge. The philosopher can do his share by approaching the scientist, and speaking his language, lead the discussion to a plane where all discussions, in the natural order, end—philosophy. Meanwhile, awaiting the re-integration of science and philosophy, western thought must make the best of a house divided against itself.

The fundamental difference between empirical and philosophical science is that the former attempts to measure phenomena while the latter proposes to examine the nature of these phenomena and their ultimate foundations. But the problem cannot be so summarily dismissed. The scientist certainly represents the object that he measures. Otherwise he should not know that it was there to measure or what type of measurement to apply—the scientist studies *something*.[22] The scientist first seeks to determine the invariant properties of the cosmos. He is only secondly concerned with the question: how much?[23] The question then arises as to the conceptual basis of science as an idea of structure and the ontal significance of this representation.

In a general sense, science tends to study matter by breaking it up. Philosophy, employing an analytico-synthetic method with synthesis playing the major role, tries to account for the union of the component parts into a substantial whole and for the ultimate intrinsic and extrinsic causes of the material universe. As Herzfeld notes, "one should say that it is the deliberate experiment which is characteristic of modern science. That means philosophically that while the Middle Ages had a preference for the 'natural state,' we think that we must first simplify the complicated conditions which occur in nature and break them down into more fundamental parts."[24] Despite the fashion of modern physics to reject the mechanical account of matter, its method is still mechanical in the broad sense of that word,[25] as we shall later see. The statement made by Lord Kelvin could still be attributed with a proper exegesis to modern physics: "I never satisfy myself until I can make a mechanical model of a thing." Physics tends to understand matter by breaking it up. In this, it is obedient to the guiding philosophical spirits of modern empirical science. Bacon advocated "a very diligent anatomy and dissection of the world,"[26] and his atomistic doctrine of forms shows more clearly

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[20] "In rebus enim sensibilibus ipsae differentiae essentiales nobis ignotae sunt; unde significantur per differentias accidentales quae ex essentialibus oriuntur," *de Ente et Essentia*, c. 5. Scientists of course do not refer to the concept of substance in their own method, but the point is that from reality's manifestations they tend to philosophize about ultimate things.

[21] Duhem, P., *La Théorie Physique*, Paris, 1914, pp. 402-3.

[22] Salmon, E. G., "Philosophy and Science," *The New Scholasticism*, 16, 1942, p. 146.

[23] Levy, H., *The Universe of Science*, London, 1932, p. 188.

[24] "The Frontiers of Modern Physics and Philosophy," *Proc. Amer. Cath. Phil. Assoc.*, 1930, p. 39.

[25] By mechanism is meant the tendency to treat being as the mere sum of its component quantities. Modern physics has challenged the accuracy of *measuring* these parts, but the fundamental concept of a material being for the physicist is still purely *partitive*.

[26] *Op. cit.*, vol. 4, p. 110.

what he means. If quantity were the essence of body, as Descartes held, then matter should be studied by dividing the quantity into parts exactly as we treat number in mathematical equations. Bodies are considered not as wholes but as sums. In its attitude toward structure, physics tends to reduce its subject-matter to terms of quantity.

The empirical sciences may be divided into two groups: the physical and the biological. The physical may again be subdivided into physics and chemistry, although "the difference between the two is fast becoming microscopic."[27] Chemistry tends to reduce its treatment of matter to the electrons of the atom which account for the chemical properties. Modern physics, on the other hand, has shifted its center of gravity from the macroscopic to the atomic world, and atomic physics is centering its attention on nuclear phenomena where most of the physical properties originate. Since the electronic phenomena of an atom depend ultimately on the number of nuclear protons, chemistry looks to atomic physics for a final answer to chemical structure. Biology follows a similar path. It studies a living thing as a physico-chemical system. Its account of structure must share the fate of the chemical and physical ones it presupposes by being reduced ultimately to the partitive phenomena studied by atomic physics. This mechanical approach to the study of life is a necessity of the experimental method, as Needham points out; it may not represent the philosophical analysis of the scientist *qua* man.[28] If experimental biology did not seek after a physico-chemical account of vital phenomena, it would surrender its title as an empirical sci-

[27] Lindsay, R. B., "The Impact of Science on Contemporary Civilization," Brown University series, "Science and the Citizen," reprinted in the *Sigma Xi Quarterly*, Jan., 1942, p. 58.

[28] "We now possess a conception of the mechanistic theory of life as a method, the method of scientific exploration, and only methodologically representing truth. Moreover, this method can be applied to no matter what. Things that do not fit into its metrical scheme can certainly not be treated scientifically, but may be none the less valid for all that: what is impertinent in Physic may yet well be inquired in Metaphysic. In the past, of course, the mechanistic theory of life has nearly always been treated as a philosophy and not as a methodological fiction," Needham, J., *The Sceptical Biologist*, London, 1929, p. 27.

ence. This philosophy of method is of fundamental importance in the solution of conflicts between science and philosophy. It may be expanded, as Needham indicates, to all of the physical sciences. "Mechanism," he writes, "cannot possibly be abandoned, for it was evidently contained potentially in the scientific method itself."[29] To measure and correlate the quantified aspects of being, the empirical scientist must by the very nature of his method confine his study to the quantified aspects of things, reducing all bodies, living or lifeless, to mechanical parts and their mechanical interactions.

As Needham indicates, the "logical" materialism of scientific method has nothing to do with metaphysical materialism,[30] nor, one may add to be more specific, has it anything to do with metaphysical atomism. Bergson recognized that positive science must assume organization to be like making a machine; it is only on this assumption that it can gain a hold on reality.[31] Whitehead has argued that "the whole concept of materialism only applies to very abstract entities, the products of logical discernment."[32] By its very nature, "methodological mechanism" applies only to that portion of the world which is amenable to its treatment. But the danger of the mechanical approach lies in the fact that it may be elevated from a methodological necessity into a philosophical dogma and extended beyond the domain where it applies. It is strictly a technique of physical science. As such, it still leaves room for a study of the world by the method of philosophy.[33]

Since, then, both chemistry and biology resolve themselves, in their last analysis of structure, to atomic physics, we can, by a

[29] *Ibid.*, p. 18; cf. also p. 84. Also: "Now scientific method, we repeat, is and must needs be mechanistic," Joad, C. E. M., *Philosophical Aspects of Modern Science*, London, 1932, p. 201.

[30] *Op. cit.*, pp. 119-20.

[31] Bergson, H., *L'Evolution Créatrice*, Paris, 1910, p. 101.

[32] Whitehead, A. N., *Science and the Modern World*, p. 111; cf. also by the same author, *Principles of Natural Knowledge*, Cambridge, 1919, p. 91.

[33] However, the traditional philosopher will not accede to Needham's thesis that the mechanical and telic accounts of reality are united by a mystical intuition. The unifying principle is that unity which is being itself and which is attained in knowledge not by mysticism but by intuition.

study of the latter branch, arrive at the ultimate analysis of matter possible within the methodological mechanism of modern science and arrive also at the meaning of this account in the light of philosophy.

III

Physics, like the other empirical sciences, attempts to measure the quantified data of the material world in order to obtain a general knowledge of their interrelationships and thus to predict future phenomena. This definition involves three important steps that represent the method of physics: 1) mensuration of quantified data: 2) general knowledge of the interrelationships of the mensurable data (theory); and 3) the prediction of new phenomena (verification).

But the method of physics begins by jumping, so to say, *in medias res*. The physicist does not approach his subject-matter with a completely passive mind. He makes presuppositions. Upon their validity, the whole structure of his science must stand or fall. These suppositions are not made in a conscious, deliberate way. They are commonplace truths to all men. They permeate so naturally and unobtrusively the procedure of the scientist, as indeed the whole life of thinking men, that they do not seem to be presuppositions. In actual practice they are not questioned. Examination of these presuppositions lies beyond the ambit of scientific method. They are postulates from epistemology, logic, metaphysics, and the philosophy of mathematics.

From epistemology the physicist accepts the existence of the external world, the validity of sense and intellectual knowledge, and the first principles of thought and being—the principles of identity, of non-contradiction, and of the excluded middle.[34]

From logic the scientist must assume the validity of discursive reasoning, the operation by which the mind passes from the relations of premises to the conclusion which such relations impose. Such reasoning is not arbitrary. It is governed by law. These laws must be sought out and proved. The view of the scientist on the nature of his science is also a postulate from logic. What is the unifying element in the science? What is its object? What is its method? Though Planck admits the need of a philosophical complement to physics, he seems to think that the physicist himself is best qualified to pass on the merits of his method.[35] But if the physicist examines his own method, he is doing so only by abandoning his empirical discipline and entering upon a field where he is no longer a physicist but a philosopher. On the other hand, if the physicist employs the empirical method to examine the empirical method, he takes the path of the infinite regress, circular demonstration.[36] The use of the philosophical method is in the legitimate scope of philosophy, just as the use of experiment belongs to the world of experimental science. Schroedinger, like Planck one of the foremost of modern physicists, recognizes the place of philosophy in examining the methods of science. He rightly insists, however, that philosophers must acquaint themselves with what the physicist does before passing judgment on its value.[37] This counsel is of great importance in present subatomic research. Probability in physics, to take only one example, is an empirico-mathematical concept that is not in conflict with either Aristotelian logic or the traditional cosmology; it simply operates on a different noematic level. But if the philosopher is to fulfill his mission as a critic of the method of science, he must acquaint himself with the way in which physicists solve such problems as those involving probability-amplitudes and statistical mechanics. Probability and statistics—terms widely used in the extremely technical domain of contemporary quantum theory—are in the last analysis dependent on philosophical interpretation. Otherwise their inner mathematical conclusions will invade—as they have so forcefully done in the minds of Eddington, Jeans, Pauli, Heisenberg,

[34] A denial of any of these three facts and principles can only lead to skepticism, idealism, and the death of science. As Planck remarks: "A science that starts off by predicting the denial of objectivity has already passed sentence on itself. Of what value to the world are the sensory impressions of a mere individual?" *Where is Science Going*, New York, 1932, p. 81.

[35] *Wege zur Physikalische Erkenntnis*, Leipzig, 1934, p. 177.

[36] The philosopher points out the escape from this circle which is the self-evident character of truths, so simple that they need no proof and so far-reaching that they are pre-supposed by any attempt to prove them.

[37] *Op. cit.*, p. 51.

and others—the region of philosophy itself. If philosophy studies the method of science, then there can no more be opposition between true science and true philosophy than between nature and true science.[38]

From metaphysics, empirical science postulates the principle of causality, the existence of plurality marked by identity, diversity, and permanence,[39] and above all the uniformity of nature. Elaborating on the concept of the uniformity of nature, Bridgman adds that science must presuppose the simplicity of nature, its finiteness, the determinateness of the future in terms of the present.[40] Even in the new quantum mechanics where the accurate prediction of the future from the past, according to the Laplacian ideal, is no longer possible, there is a form of prediction (in psi-functions), very accurate indeed, where the fate of a mass of particles is known, even if this or that individual cannot be mathematically described. "Probability amplitudes," as will be shown, represent order, a determinateness. In a disordered world, science would be impossible.

From the philosophy of mathematics, the scientist must be acquainted with the nature and scope of mathematics and its relation to the real world. Are the complex number and mathematical infinity real beings? Is non-Euclidian geometry a being of the reason? These, Maritain points out, are samples of questions in the philosophy of mathematics which the physicist must either treat philosophically for himself or pre-suppose as answered by the specialist in philosophy.[41] There are other questions in the philosophy of mathematics which the physicist must postulate for his empirical study, including of course the fundamental guarantee of a mathematical equation as found in ontology and theodicy.[42]

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[38] Benjamin, A., *An Introduction to the Philosophy of Science*, New York, 1937, p. 22.

[39] Becher, E., *Philosophische Voraussetzungen der exakten Naturwissenschaften*, Leipzig, 1907, p. 112.

[40] Bridgman, *The Logic of Modern Physics*, New York, 1927, pp. 197 ff.

[41] *Les Degrés du Savoir*, Paris, 1932, p. 100.

[42] What Laplace may have meant by his supposed remark to Napoleon that in his *Mécanique Céléste* he had no need for the "hypothesis" of God, we find it necessary to return to God if we are to guarantee our certitude;

Such are some of the presuppositions of physics. If the scientist is not to proceed on blind faith as Dotterer seems to suggest,[43] if he is to have a rationally justified method just as he seeks rational justification for every step in the actual employment of his method, then the presuppositions must be examined by the non-empirical science which is philosophy. We find therefore that physics is incomplete at the outset. It must postulate principles from philosophy before the scientific method, properly speaking, can begin work. Otherwise, it would be beginning in an arbitrary way and would be risking its whole superstructure on assumptions made at the outset, without their submission to the rational examination of philosophy. No conclusion is stronger than its premises.

Once these postulates are established, the physicist can deploy his method of measurement, correlation, and prediction mentioned above. This division of the scientist's activity may be another of those over-simplifying generalizations about scientific method unless it is properly interpreted. Besides finding subdivisions in the three steps, their frequent overlapping, and shifts in the order of their application,[44] one may discover the persistent obtrusion of the scientist's intellectual activity, as a man, through his technical procedure as a scientist.

Measurement, for example, involves much more than the mere act of observing coincidences between calibrated scales and the activity of matter. The scientist must first of all select his data. For though in a certain sense, physics proceeds by a trial-and-error method, yet the range of questions is limited by the scientist's foreknowledge, based on experience and on an intellectual analysis of a given problem, of the type and magnitude of the measured answers that are likely. Millikan knew, for example, when he measured the charge on the electron that he should use a voltmeter, and not a stethoscope, to record the force necessary to raise his oil-droplets against the force of gravitation. Theory is inter-

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for nothing can ever be true unless there be truth. No act of composing and dividing, be it a judgment or an equation, can ever be true unless there is a being simply and subsistently true.

[43] *Philosophy by Way of the Sciences*, New York, 1929, p. 124.

[44] Naville, E., *La Logique de l'Hypothèse*, Paris, 1895, p. 68.

woven with experiment. But the two are certainly not the same in their precise senses. So bearing in mind that they often go hand in hand, we are justified in distinguishing their respective roles for purposes of study.

Nor is the contemporary attitude toward experiment without its past parallels. Experiment was described by Aquinas, developing Aristotle's thought on the subject, in a very striking way. It owes its origin, he says, to the remembrance that certain facts have been noted time and again in connection with a given thing. It proceeds as a type of reasoning concerning particulars. Thus, Aquinas goes on, when a doctor has observed that a certain herb has cured many individuals of fever, he accepts as a principle of his art and science that this herb is a cure for fever.[45] The doctor undoubtedly tried other medicines before he hit upon the right one. When he discovered that the herb was successful in one case, he prescribed it for others before arriving at a general principle. This description is echoed in the words of Eddington who points out, though with a savor of subjectivism, that scientific knowledge arises from the association of certain memories of past experience.[46] What Aquinas thought on the subject of experiment is in remarkable harmony with the method of modern science. Lindsay and Margenau, discussing experiment from the point of view of contemporary physics, declare that experiment involves: "(1) the abstraction from the totality of experience of a small domain for special investigation; (2) the presence in the mind of the experimenter of ideas relating to this domain leading him to frame certain questions the answers to which he seeks; (3) the operational character of the experiment involving well-defined activity on the part of the experimenter."[47]

The first point in the foregoing definition cannot be italicized too much in view of the significance it has for a correct understanding that the field of scientific inquiry and the method of scientific procedure do not embrace the totality of being and of knowledge. Forward-looking physicists are quick to admit that

[45] *In II An. Post.* 20.
[46] *The Philosophy of Physical Science*, p. 189.
[47] *The Foundations of Physics*, New York, 1936, p. 5.

they are dealing with only a small part of the real world in their experiments. Eddington, impressed with the circumscribed nature of modern physics, speaks of "selective subjectivism" by which we limit the field of physical inquiry and then limit our method of studying the field itself.[48] As it has often been put, modern physics with its specialized branches and specialized techniques tends to learn more and more about less and less. The whole point is of capital value for a critique of the sciences. It is evident that if physics studies only a small portion of the real world, there is need for a science of the totality which is philosophy.

The experimenter, Lindsay and Margenau continue, has certain preconceived questions. As Aquinas says, in experiment there is a remembrance of past impressions. Philosophy, as Plato and Aristotle noted, begins in wonder. This is also true of the empirical sciences in their knowledge character. But man has more than a vague curiosity. He wants to know particular causal conditions. Experiment becomes "nature's answer to man's questions."[49] In a wider sense, however, nature is only the means by which man answers his own questions. Much of our data in atomic physics, for instance, are derived from spectroscopy. The spectra of the various elements are, for example, correlative with their positions in the periodic table; they have even predicted elements discovered later. But these are not only conclusions from the data themselves. They are nature's language decoded by the physicist. In this light, Duhem was right in insisting on the role of interpretation in experiment.[50] Not only does man answer his scientific questions by interpreting an experiment performed on nature. He has an idea beforehand of what the answer is likely to be. This anticipation of nature is aided by hypothesis.[51]

Finally, Lindsay and Margenau call attention to the operational character of the experiment. This operational aspect arises from

[48] *Op. cit.* (*passim*).
[49] Dingler, H., *Das Experiment*, Munich, 1938, pp. 39-40.
[50] *Op. cit.*, pp. 111 ff.
[51] "Normally, an experiment is performed for the sake of verifying an hypothesis; hence, there is a definite control of the set-up and an anticipation of the outcome." Benjamin, *The Logical Structure of Science*, New York, 1936, p. 271.

our attempt to measure phenomena. It imposes obvious limitations on the scientist to remain strictly within empirical bounds according to his own canons of verification. Operations, when they are of the physical type, are also of capital importance in view of what Herzfeld has called "the deliberate experiment which is characteristic of modern science."[52] Aside from the problem of eliminating such extraneous forces as gravitation and electrostatic action where their effect is not directly pertinent to the outcome of an experiment, there is a persistent source of error arising from the interference of measuring instruments with the subject of study. This fact is embodied in the Heisenberg principle of indeterminism which states that it is impossible to measure the position and momentum of a particle simultaneously and that therefore the question of the simultaneous location and velocity of a particle has no meaning in physics.

All experiments involve isolation of elements from the complexus of reality. An experiment is a controlled sense-perception which simplifies the variables of a problem. But we can never boast of the complete isolation of our subject-matter. We cannot extract a single phenomenon from nature, eliminating all outside influences. In our operations, we may by a suitable apparatus cut down the effect of interfering factors to a negligible point, or we may correct for the interference by mathematical means. But there is no strictly isolated system except the whole universe.[53]

Finally, an experiment must be repeatable according to the demands of universality and objectivity which are the pre-requisites for any science, philosophical or empirical. In a practical way, this repetition is fraught with serious problems.[54] Though two experiments may be sufficiently alike to be practically identical, we may nevertheless remember their differences in our employment of the phrase "exact science." It was not necessary for

[52] Cf. *supra*, p. 8.

[53] Levy, H., *op. cit.*, p. 52.

[54] "Unfortunately, we cannot repeat an experiment under exactly the same conditions. The time of the day, the season of the year, the past history of the bodies operated on are subject to incessant change. No two experiments can truthfully be said to occur under exactly the same conditions," d'Abro, A., *The Decline of Mechanism*, New York, 1939, p. 17.

Aquinas, in his discussion of experiment, to lay stress on the problems arising from the operational character of the example he used. He was not dealing with reality from the point of view of measurement. This approach to reality, as Bergson has pointed out, is the distinguishing feature of modern empirical science.[55]

The foregoing pages have presented an historical summary of the attitude toward physics since it emerged from the traditional synthesis of knowledge. In the discussion which followed, the general characteristics of the so-called scientific method, its postulates and its central theme, experiment, were sketched. This introductory definition of the empirical method has already led us to important frontiers. The logical procedure of physics may now be examined in more detailed form.

[55] *Evolution Créatrice*, p. 360.

CHAPTER II

Measurement in Physics

The purpose of empirical inquiry is to discover and measure the relationships of phenomena. The physicist is not concerned with the beauty of the rosy-fingered dawn that attracted Homer or with the "plaintive anthem" of the nightingale that enraptured Keats. He is interested in the refraction of the light and in the amplitude and frequency of the sound. He is concerned with measurement.

Measurement may be treated, for the sake of convenience, under six headings: 1) the description of measurement; 2) the limits of measurement in its object; 3) the limits of measurement in its method; 4) statistics as a substitute for exact measurement; 5) the results of measurement—equations; and 6) scientific law.

Measurement is the process of correlating numbers with things that are not numbered.[1] It consists first in the assignment of suitable units to material, quantified phenomena, and, secondly, in the computation, by proper mathematical operations on these units, of related magnitudes.

All instruments involve the registering of results, however heterogeneous they may be in their ontal status, by geometrical means. Whether we employ an ordinary yardstick, a thermometer, an analytical balance, a spectrum, or a Geiger counter which measures radioactive decay by means of an electrometer, the readings involve the spatial coincidence of a point or line with a mark on a calibrated scale. Even such a magnitude as the velocity of light was computed by Michelson from the comparison, with time, of the reflections of a beam of light falling on a rotating mirror. Both the angular rotation of the mirror and the time were measured geometrically.[2]

[1] Cf. Nagel, E., *On the Logic of Measurement*, New York, 1930, p. 37.
[2] Ritchie, A. D., *op. cit.*, p. 125.

Eddington writes: "Whether we are studying a material object, a magnetic field, a geometrical figure, or a duration of time, our scientific information is summed up in measures; neither the apparatus of measurement nor the mode of using it suggests that there is anything essentially different in these problems."[3] Hence, Eddington reduces physics to a science of pointer-readings.

But we cannot accept Eddington's generalization. To say that physics is only a science of pointer-readings[4] is another of those over-simplifying solutions of the relation of science and philosophy that have only complicated the real problem. Measurement involves a theory of what takes place in the measuring instrument.[5] How can we correlate geometry with electrostatics, radioactivity, temperature, pressure, and the like—unless we have, by insight and reasoning, reached a knowledge of the interrelation of the readable results on a graduated scale and the phenomenon we measure?[6] There is something more than pointer-readings.

Heisenberg has rightly pointed out that in contemporary atomic physics instruments and theories are mutually dependent.[7] In building our apparatus, a theory of the measured object is presupposed. This is illustrated in the complex atom-smashing machines now in use, the Van der Graff generator and the cyclotron. It was only with the advance of atomic and electrical theory that such instruments became possible. To take another example, Aston devised a way of measuring the masses of various isotypes by observing the deviations of the positive ions of elements in electric and magnetic fields. But the method involved many theoretical considerations besides the mere observation of recording photographs, the analogues, in these experiments, of Eddington's pointer-readings. Anderson's discovery of the positron would

[3] *The Nature of the Physical World*, Cambridge, 1933.
[4] *Ibid.*, pp. 251 ff.
[5] Planck, M., *Where Is Science Going?* p. 97.
[6] ". . . no amount of description of things can tell us what anything is for. There is nothing in any law of Physics to tell us that a clock is for keeping time. The laws of nature tell us that the hands go around at a particular uniform speed and that is all," Ritchie, A. D., *op. cit.*, p. 182.
[7] *Wandlungen in den Grundlagen der Naturwissenschaft*, Leipzig, 1936, pp. 16-18.

never have been possible if he had not had the insight to interpret in terms of something non-geometrical the geometrical paths of particles shown on a photograph.[8] Eventually, measurement involves a judgment about the qualitative world where all our knowledge begins.

To speak of physics as a science of pointer-readings is a confusing definition that puts the physicist in the same class with the motorist reading his speedometer and the railroad engineer watching his pressure-gauge. Mensuration is only the formal object of physics, the point of view taken on the subject-matter. The subject-matter, or the material object, is the corporeal world. As Maritain has insisted, contemporary physics is a type of *scientia media,* formally mathematical and materially physical, which was described by Aristotle, Aquinas, and Cajetan.[9] Physics studies the material world in its mensurable aspects. Experiments on matter, interpreted by physical insight, form a legitimate and necessary means of realizing the fullness of the formal object of physics, mensuration. Mensuration is enriched and multiplied in this way.

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[8] Planck has summed up the case thus: "Eine Methode physikalischer Messung aber, bei der jewede auf Induktion beruhende Erkenntnis ausgeschaltet ist, existiert überhaupt nicht; das gilt auch für die direkte Wägung. Ein einziger Blick in ein Präzisionslaboratorium zeigt uns die Summe von Erfahrungen und Abstraktionen, welche gerade in einer solchen scheinbar so einfachen Messung enthalten ist," *Wege zur Physikalischen Erkenntnis,* p. 29.

[9] Maritain, J., *op. cit.,* pp. 83-84; cf. also by the same author, "The Conflict of Methods at the Close of the Middle Ages," *The Thomist,* 3, 1941, p. 530. St. Thomas writes: "Quilibet cognoscitivus formaliter quidem respicit medium per quod aliquid cognoscitur; materialiter autem id, quod per medium cognoscitur; et quia id quod est formale, potius est, ideo illae scientiae quae ex principiis mathematiciis concludunt circa materiam naturalem, magis cum mathematiciis connumerantur, utpote eis similiores, licet quantum ad materiam magis conveniant cum naturali; et propter hoc dicitur in II Physic. quod sunt magis naturales." II-II, 9, 2 ad 3. Commenting on this passage, Cajetan adds: "Non dicitur quod scientiae mediae sunt magis mathematicae quam naturales; cum falsum sit absolute loquendo; quia simpliciter sunt scientiae naturales, utpote non abstrahentes a materia sensibili. Omnis enim scientia non abstrahens a materia sensibili est naturalis, ut patet VI Metaph. Sed dicitur quod connumerantur magis cum mathematicis, utpote eis similiores."

But physics is not only pointer-readings. It is precisely because he neglects the material object, *that which* is studied, and defines physics only from the viewpoint of its formal object that Eddington reaches his extreme view. So also Jeans, if we have interpreted his thought correctly, seems to place the essence of reality in mathematics.[10]

Bergson, with another end in view, insists on the symbolic character of physics. Though we may disagree with his philosophy of *la durée pure,* he nevertheless pointed out very forcefully against the positivism of his time that physics represents the world only in terms of mathematical symbols and thus is asymptotic to the essence of the real. Time in physics, he argued, is measured by the trajectory of a moving point *t*. For the scientist, time is a line in space.[11] Time for the physicist is therefore spatialized. The same criticism applies to movement in general. Physical science tends to reduce motion to the immobility of positions on mathematical lines.[12] Bergson admitted the existence of a real world. What he denied was that physics discussed its real nature.

Bergson applied his searching criticism also to the four-dimensional space-time continuum proposed by Minkowski and incorporated into the theory of relativity. This idea has caused so much misunderstanding because by it space and time, for modern thought, became confused with their symbolic representation.[13] Pointing out that the four-dimensional continuum is only a sym-

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[10] ". . . the final truth about a phenomenon resides in the mathematical description of it. . . ." *The Mysterious Universe,* New York, 1937, p. 176; also: ". . . the universe can be best pictured, although still very imperfectly and inadequately, as consisting of pure thought, the thought of what, for want of a better word, we must describe as a mathematical thinker," *ibid.,* p. 160.

[11] *La Pensée et le Mouvant,* Paris, 1939, p. 9.

[12] *La Durée et Simultanéité,* Paris, 1923, p. 69.

[13] Eddington, for instance, in spite of his insistence that physics is purely metrical and a record of pointer-readings, starts out his most famous work, *The Nature of the Physical World,* with the misleading statement: "Between 1905 and 1908, Einstein and Minkowski introduced fundamental changes in our ideas of space and time." This is a false or at most equivocal statement. Relativity did not introduce changes in the ideas of space and time but only in our measurement of the two realities.

bolic expression, Bergson declares that it says nothing "new about space and time: these remain what they were, distinct from one another, incapable of being united except by means of a mathematical fiction, intended to symbolize a physical truth."[14] Though he erred in his idea of the nature of ultimate material reality, Bergson admitted its existence. His criticism of positive science as a merely symbolic study of the metrical aspects of this ontal world will remain as one of the weighty contributions of his genius to France and to philosophy. The real world forms the subject-matter of physics; the symbols are merely involved in its point of view.

From one aspect, measurement seems to involve a vicious circle. Classical mechanics, for instance, is reducible to Newton's three laws.[15] Is it a mere pleonasm to say that force equals mass times acceleration? D'Alembert, Lagrange, Hamilton, and others attempted to lay the basis for mechanics in various other ways. D'Alembert, for instance, reasoning from an equation of equilibrium, set up a formula in which actual motion was defined as the resultant of impressed motion and of the constraint of factors which did not leave the impressed particle free to act. At first sight this seems to be tautology. But it is merely a definition of an elementary standard of measurement that permeates all succeeding operations. This condition is as it should be. Mechanics is formally a mathematical science. Unless we are to fall victim to an infinite regress, we must come to a point where definition

[14] *Op. cit.*, p. 234. The word "fiction," however, will be qualified when we come to discuss the relation of theories to reality. Here it need only be noted that since Relativity tensor equations only measure reality, they are silent about matter's ontic structure.

[15] Newton's first law of motion states that every body continues in its state of rest or uniform motion, except in so far as it is compelled by forces to change that state. Eddington argues that since force defines motion and motion, force in Newton's concept, the first law means: "Every body continues in a state of rest or uniform motion in a straight line, except in so far as it doesn't," *op. cit.*, p. 124. Newton did not, however, mean to define force in this way. He assumed that the idea of force was known to common sense from the physiological reactions experienced in a push or pull. It is the aim of contemporary physics to eliminate these so-called "anthropomorphic" elements.

replaces demonstration as a source of knowledge.[16] Definition is not nonsense but based on direct evidence as opposed to the indirection of demonstration.

In this connection, Eddington has argued that all physical concepts are interlocked in a "cyclic method" of definition. "Electric force," he writes, "is defined as something which causes the motion of an electric charge; an electric charge is something which exerts electric force. So that an electric charge is something that exerts something that produces motion of something that exerts something that produces . . . ad infinitum."[17] A circular definition is neither intelligible nor useful. It merely repeats the concept to be defined, and the problem of definition remains.

But Eddington's view is grounded on a misconception. Physics does not proceed from circular definitions. To define is basically a process of apprehension or mental analysis. In such an operation, it may be agreed with Riezler that the "relation (child-father) is prior to the relata. You do not define one by means of the other but each by means of a whole that is articulated within itself."[18] The whole is grasped by abstraction. Force and charge, like the motive and restraining forces in d'Alembert's equation, are defined in terms of the totality which the mind apprehends. Hence there is no vicious circle. There is a meaningful definition. Eddington's difficulty seems to spring from the belief that the mathematical alone is meaningful. This is a gross misconception. Even in physics, mathematical reasoning must be preceded, accompanied, and followed by intellectual insight into realities and relations that give meaning to the mathematics. Though physics may define its material in terms of mathematical functionality and not of essential

[16] This bears witness to the fact that science is not completely inductive, induction being a type of argument. Nor is philosophy wholly deductive and syllogistic. The idea of being is attained not by demonstration but by direct insight. Without reference to this idea, neither philosophy nor physics is intelligible.

[17] *Op. cit.*, p. 264.

[18] Riezler, K., *Physics and Reality*, New Haven, 1940, p. 102. This whole problem is provoked by the demand of the Positivist spirit that even the obvious, which can be grasped by direct, immediate apprehension, be made a matter of demonstration.

relations, the same *logical* operation is involved as when, for instance, we define man. It is the same, from the point of view of *formal* logic, to recognize that man is a rational animal as to recognize that $y = f(x)$.

Measurement was defined as a type of correlation between numbers and the non-numbered. The correlation is the most important fact. Numbers assigned to the various quantities may differ according to the scale employed—whether, for instance, it be the English or metric system, centigrade, Fahrenheit, or absolute temperature, the micron or the Angstrom unit. The fundamental element is not the numbers but the ratio between them which is the same in whatever measuring system we employ.[19] Ratios can be conveniently expressed in terms of functionality and resolved into the form of differential equations. One quantity is said to be a function of another if, when the second takes on a value, the first takes on a corresponding value. Functions may be combined in parametric form; they may be expressed in terms of other variables. But there is still the same method of evaluation, the same interrelationship, so that when one function (or one variable) is assigned a value, the other functions (or other variables) take on corresponding values. Functionality, embodied in differential equations, is the usual form of expressing the results of measurement in physics.

Nature does not measure, does not count, Bergson wrote.[20] But if our meter-sticks and stop-clocks are standards relative to man, present-day physics believes to have found a way of measuring the *absolute* space-time relationships in the theory of relativity.

The theory has its origin in the Michelson-Morley attempt to measure the ether-drift, an experiment which proved that the velocity of light is constant: that, for instance, whether the earth is moving toward the sun or away from it, the relative velocity of the light is the same.[21] The Lorentz-Fitzgerald contraction theory attempted to account for this deviation from known laws of composition and resolution of velocities; it supposed that a body moving through the ether contracted in a direction parallel to its movement by an amount sufficient to account for the results of the Michelson-Morley experiment.[22] Lorentz also set up a series of equations to transform co-ordinates from one frame of reference to another, according to the contraction theory.[32]

Then, in 1906, Einstein announced his special or restricted theory of relativity. Prescinding from the question of the existence of an ether, he made two far-reaching assumptions concerning uniform translatory motion: a) that there is no unique or privileged co-ordinate system but that any observer in relative motion may consider himself at rest and use this frame of reference in his observations; and b) that the velocity of light is independent of the motion of the observer.[24] Einstein's statement of the relativity of motion makes it permissible to say interchangeably that the moving body A is in motion relative to B or that B is moving relative to A. His arguments on time sum up to the conclusion that there is no absolute simultaneity but only simultaneity relative to a given frame of reference. Without accepting the contraction

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[19] Bridgman, P. W., *Dimensional Analysis*, New Haven, 1936, p. 13; cf. also Campbell, N. R., *Measurement and Calculation*, London, 1938 (*passim*).

[20] *L'Evolution Créatrice*, p. 239.

[21] This is not what we should expect according to the ordinary laws of the composition and resolution of velocity. If A is moving forward five miles an hour in a train that is moving in the same direction thirty miles per hour, he would be travelling forward at the rate of thirty-five miles per hour. If B is on a train travelling thirty miles an hour and if he is walking against the direction of the train with a velocity of five miles per hour, he would be moving forward at a rate of twenty-five miles per hour. The significance of the Michelson-Morley experiment, then, is this: if A and B represent the light and the earth is the train, the velocity of A and B is exactly the same in both cases.

[22] Writing of the Lorentz-Fitzgerald contraction theory, Einstein says: "But on the basis of the theory of relativity the method of interpretation is incomparably more satisfactory. According to this theory, there is no such thing as a 'specially favored' (unique) co-ordinate system to occasion the introduction of the aether-idea, and hence there can be no aether drift, nor any experiment with which to demonstrate it," *Relativity*, New York, 1931, p. 63.

[23] Lorentz, H. A., "Electro-magnetic Phenomena in a System Moving With Any Velocity Less than that of Light," in Lorentz, Einstein, Minkowski, Weyl, *The Principle of Relativity* (A Collection of Original Memoirs on the Special and General Theory of Relativity), London, 1923, pp. 11-34.

[24] Einstein, A., "On the Electrodynamics of Moving Bodies," *ibid.*, pp. 37-55.

theory, Einstein was nevertheless able to incorporate the Lorentz transformation into his theory to account for changes from one frame of reference to another.[25] The theory of relativity, as Langevin and Sullivan have stated, is in reality a theory of absolutes since it discovers invariants in the changes from one inertial system to another.[26]

The general theory of relativity—generalized to include bodies in rotational motion and therefore containing the restricted theory as a special case—is an attempt to grasp the universal, fundamental metrical relations of the material world. It introduces a new concept of field and aims to combine gravitational and electromagnetic phenomena in one relation. But in the theory of relativity, gravitation and electromagnetism are clothed in new form. They are not properties of bodies. The Newtonian concept of gravitation can be considered as the equivalent of a properly accelerated system in space. Newton's law, according to relativistic principles, views the world in terms of Euclidian geometry, it therefore holds only in ordinary, apparently Euclidian space. If on the other hand we construct a geometry based on the Gaussian arc elements—in which space is regarded as curved—the laws of motion can be derived in universal form without reference to gravitational forces. The mathematical technique is that of the tensor calculus which, it is said, enables relativity mechanics to read down to the fundamental properties of matter.[27] Just as there is no absolute motion, so there is no absolute acceleration. But the invariants in changing from one frame of reference to another can be computed from the tensor calculus. The general theory of relativity purports to combine gravitational and electromagnetic properties of the material universe as properties of space and to interpret these in terms of geometry.[28] But the general theory of relativity, as Bergson said, is, like all other physico-mathematical systems, a symbolic representation of the metrical aspects of matter. It is

[25] *Relativity*, p. 51.
[26] Born, M., *Einstein's Theory of Relativity*, London, 1924, p. 246.
[27] Nagel, E., *op. cit.*, p. 71.
[28] Einstein, A., *The Meaning of Relativity*," London, 1932, p. 62.

not an ontology of nature.[29] It is a system of measurement. Mathematics only touches the quantity in matter. The physical aspects of the theory of relativity only simplify and suggest measurements. The essence of matter is in another order.

It may be added, just to complete the relation of Einstein's theory to measurement, that relativistic corrections demanded by the restricted theory need only apply where velocities are very high. The general theory, which formulates the Newtonian concept of gravitation in more universal form, also agrees very closely with Newtonian mechanics in ordinary space. Its value as a theory lies in the fact that it covers phenomena in interstellar spaces where Newtonian mechanics does not hold; it therefore includes Newtonian mechanics as a special case by restricting its field of application. But relativity, though it need not be applied where its corrections would be negligible, is nevertheless theoretically involved in every process of mensuration in modern physics.

Measurement has its own peculiar presuppositions. It must postulate 1) the homogeneity of the measured object; 2) its divisibility, as indicated by the units of the graduated instrument; 3) the permanence and fixity of the measurable species; 4) the invariance of dimensions; 5) the continuity of the object; 6) its spatial objectivity.[30] These are not empirical questions. If they are treated on an empirical level, the result will be a vicious circle.

What does physics measure? In the strict sense of the word, as Aquinas says, only quantity can be measured. All other mensurations have reference to operations on quantity.[31] This statement is in accord with the view of present-day physicists. As Herzfeld writes, "any statement to the physicist has meaning only if it is

[29] Cf. *supra*, p. 25. Also: "But relativity teaches nothing about the matter of events as distinguished from their spatio-temporal forms: nothing, that is, about lights and colours, the sounds, the odours, the hotnesses and coldnesses and so forth which we experience in space-time. For all that it has to tell us, these things may be of the very stuff of the universe," Nunn, T. P., "Anthropomorphism and Physics," *Proc. Brit. Acad.*, vol. xiii, 1926, p. 7.
[30] Spaier, A., *La Pensée et la Quantité*, Paris, 1937, pp. 322 ff. Though the author believes that quality itself can be measured, a view that will be considered below, his analysis of the postulates of measurement apply to the consideration of measuring quantity.
[31] *In Met.*, 10, 2, 1938.

quantitative."[32] Quality escapes measurement. It is an attribute that flows from form. It does not, as far as it is quality, proceed from the material component of corporeal being. Aquinas defines it as a mode of substance, a disposition of substance, a determination of substance, it does not order material parts in the manner of extension. It is a perfecting, actualizing attribute in the order of form. As a formal attribute, it is not subject to the laws of inertia that govern purely mechanical systems of physics, according to Newton's mechanics. Hence, by its function as an actualizing property on the level of form, it enables physics to avoid the infinite regress dictated by Newton's first law where all is inert and nothing is actualized.[34]

Quality as quality escapes physics. It does not, however, escape the physicist. His mental analysis bears upon the qualitative world of sensation. His system of measurement is built up from, and applied to, his observations of qualitative resemblance and difference. Quantity is only the plurality of parts. It is therefore always a quantity of *something* to which the parts belong. No scientist begins his work with mere plurality as such. He specifies the pluralized something (material object), without which the world of thought and of being would be unintelligible. He studies this material from the point of view of quantity. In the classification of phenomena, the physicist appeals to the qualitative order, especially in the early stages of his science. The distinction between positive and negative particles, waves and corpuscles, matter and energy, and the like are ultimately based on an insight into quality.[35]

In the fact that quality as such is not tractable in experiment lies one of the most important limitations of physics. Physics tends, Meyerson says, to reduce the qualitative world to the inertia of mere space.[36] Or as d'Abro has remarked, "The objective universe of science is thus noiseless, lightless, odourless."[37]

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[32] *Art. cit.*, p. 40.
[33] I, 28, 2; I-II, 49, 2.
[34] John of St. Thomas, *Cursus Philosophicus*, Turin, 1937, vol. 1, p. 609.
[35] Cohen, M. and Nagel, E., *An Introduction to Logic and Scientific Method*, New York, 1934, p. 224 and p. 243.
[36] *Op. cit.*, p. 186.
[37] *The Evolution of Scientific Thought from Newton to Einstein*, New York, 1927, p. 412.

Quality, however, in a derivative sense does not completely elude the empirical method. As John of St. Thomas says,[34] quality determines quantity. All the objects of our sensation are, precisely because they are extended in material subjects, quantified qualities with the quality, according to the exigencies of its nature as a formal accident, determining the quantity which is the first and most characteristic accident of matter and the proximate subject of inherence for all others. It is possible then, by a study of the determined, quantified aspects of quality to arrive at some knowledge of its formal, qualitative determinant. Here we have a clue to justify the scientific method and to explain its success. It does not study heat, work, electricity, color, sound, and magnetism as formal qualities but only reaches their quantified aspects, their mechanical equivalents in the language of Boutroux.[38]

Matter is the vehicle of superior qualities. By a study of the vehicle, we can learn something of the qualities. When we study the quantified aspects of quality, we have not exhausted the fullness of quality itself. The mechanical equivalent of a thing is not the thing itself.[39] The two orders may be correlated without being identified. Loudness, for example, is determined by wave amplitude. Pitch is a function of wave length. By quantitative variations in each case, experiment achieves corresponding variations in the qualitative effects. This, however, does not justify the conclusions that the quantitative treatment of loudness and pitch has exhausted their realities. The wide use of such concepts as the Hamiltonian or the Laplacian in modern physics tends to throw into relief the homogeneous aspects of material phenomena which appear qualitatively different to common sense and to the realist in philosophy. But granted the validity of the quantitative approach which detects the common elements in such diverse fields as electrodynamics and hydrodynamics, light waves and matter waves, electromagnetism and gravitation, we have by a quantitative study by no means accounted for the qualitative heterogeneity of the related phenomena.[40]

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[38] *La Contingence des Lois de la Nature*, Paris, 1929, pp. 63-4.
[39] *Ibid.*, p. 71.
[40] Nagel, E., *op. cit.*, p. 29.

Nagel has divided quality into additive and non-additive types.[41] But addition, strictly speaking, can apply only to the quantitative aspects of quality, not to the quality in itself. If we add weight to weight or light waves to light waves we can calculate by arithmetic addition and subtraction what the result will be. But we cannot do so with such properties as density, temperature, hardness, viscosity, compressibility, and the like.[42] The difference in such qualities from one substance to another affords proof that, though we may represent quantitative aspects of quality in mathematical formulae, our measurements have not exhausted their noetic plenitude. There is in matter a formal element which is not quantity and which the scientific method is consequently forced to ignore.[43]

Finally, it is only being realistic in the study of the physical world to define the scope of a science and then adhere strictly within the limits imposed by the definition itself (in the order of knowing) because they arise from the reality defined (in the order of being). The material world is a world of quantified quality. By its formal object, physics studies the quality only as quantified. This distinction justifies the procedure of physics. It also leaves room for the philosophical complement which physics cannot undertake but which looks, from another point of view, at the same subject matter.

Having seen the metaphysical limitations of measurement in its object, we turn now to the logical limitations of the process in its method. This involves two questions of particular importance: the general approximate character of measurement and the principle of indeterminism.

Our instruments of measurement are divided and subdivided into various units that we apply to the physical world, whether

[41] *Ibid.*, Chapter II.

[42] Campbell, N. R., *op. cit.*, p. 277 and p. 283.

[43] Here is a point where philosophy makes up for the inadequacy of physics. "For natural philosophy," Whitehead writes, "everything is in nature. We may not pick and choose. For us the red glow of the sunset should be as much part of nature as are the molecules and electric waves by which men of science would explain the phenomenon. It is for natural philosophy to analyze how these various elements of nature are connected," *Concept of Nature*, p. 29.

as pointer-readings, meter-sticks, or points on a geometrical curve. By the very nature of the process, we arrive at discrete results, even when we are applying measurement to a continuum.[44]

On the other hand, we sometimes treat discrete data as continuous. In verifying such a simple principle as Boyle's law in physical chemistry, we may plot pressure against volume in a number of experiments with different elements; we then draw the smoothest possible curve to connect the points for the purposes of formulating the law.[45] Yet the original points, because of experimental error, may not all fall on the curve; indeed none of them might do so. Again, in dealing with a discrete medium of particles, we may, provided each element of volume contains a large number of corpuscles, regard the medium as continuous for purposes of mathematical analysis. Even in quantum theory, large aggregates of particles may be viewed as continuous and determinism again prevails.[46] In a practical sense this procedure is wholly justified. Yet at its best it can only yield a high degree of approximation.

When we are measuring length in the macroscopic world, we are oftentimes content with knowing centimeters, we do not regard the fractions that might result if the instrument were an eyepiece micrometer measuring in terms of microns. Or suppose, to take another example, that two men are asked the temperature of a given room. They might differ by a wide margin in their responses, and so a thermometer would be consulted to give the answer. They might read the result and accept the verdict of the instrument. But if we calibrated the instrument down to fractions of degrees and then to fractions of fractions, the difference in perception of the two men would again yield different answers. The thermometer has certainly refined and corrected the crude, common-sense conjecture on the temperature of the room. It has reached a degree of accuracy that is wholly satisfactory for practical purposes. But we must say that even the thermometer readings can only be interpreted as very high approximations.

[44] Schroedinger, *op. cit.*, pp. 72 ff.

[45] Lindsay and Margenau, *op. cit.*, pp. 14 ff.

[46] d'Abro, A., *The Decline of Mechanism*, pp. 183-5.

In this light, Whitehead has pointed out that one of the chief causes of the advance of science has been the development of scientific instruments in modern times.[47] This has led to a strong faith in the value of our instruments. After all, so long as men relied on the eye alone, it is said, observations were always subject to differences in visual accuracy: so also with all the senses. But the reading of an instrument is still the work of the eye. That there is no difference in the pointer-readings of two men is due not necessarily to the exact parallel of their vision-strength but perhaps to the imperfections of the instrument itself.[48] If it were calibrated finely enough, no two men might read it alike. As Eddington has said, no matter how finely we scale our degrees of accuracy, "molar physics has the last word in observation, for the observer himself is molar."[49]

Secondly, to make perfect instruments requires instruments equally delicate. How are we to make sure that two of them are exactly alike? Instruments are helpful tools and have reduced the margin of error in our measurements. But they are not perfect. We must continue to speak of phenomena in terms of approximation carried out to new decimal points but never measured with reliable accuracy in an absolute sense. The use of instruments to check the accuracy of instruments involves a vicious circle if the process remains on the purely empirical level. To escape from it, we examine by another method the sense perception which originates the process of measurement, participates in the checking of instruments, and finally takes the pointer-readings themselves. The differences in perception may still leave room for material inexactitude. However, the method of measurement can be formally

[47] *Science and the Modern World*, p. 161 ff.

[48] Whitehead, distinguishing perceptual objects, sense objects, and scientific objects, calls attention to the differences of perception, among men, on the level of perceptual objects, *Principles of Natural Knowledge*, p. 86. But even if his divisions and definitions were entirely correct, the refined character of our knowledge of scientific objects has not solved the problem of inaccuracy. These objects are subject, through the approximate character of every measurement, to the same inaccurate treatment which characterizes our measuring of macroscopic objects like a table. Our instruments have simply reduced these inaccuracies.

[49] *The Philosophy of Physical Science*, p. 77.

justified by being placed beyond the enclosure of a vicious circle. Man's self-knowledge makes him subject and object of his own actions. This may be called anthropomorphism. The appeal to sense perception, studied and examined by philosophy, may be termed a meaningless question by Bridgman and the Viennese school, since it does not submit to checking by the scientific method. But without it, we cannot have science, much less a rationally founded science.

The factor of interference is an important curb on the accuracy of measurement. In the macroscopic world, the physicist points out, the margin of error is so small that it makes no practical difference in the end result. But in the microscopic world, the factor of interference is important. Suppose that we are trying to measure the path of alpha rays by the cloud-chamber method designed by C. T. R. Wilson. This is done by indirect means. The principle employed consists in this, that when a gas, saturated with moisture, is quickly expanded, condensed vapor is formed. The alpha particles ionize the atoms of the gas along their tracks; at the sudden expansion minute drops are condensed on the ions. If the drops are immediately illuminated by an electric spark, they can be photographed. They thus represent the path of the alpha particles. But what have we actually measured? The path of the particles has certainly been deflected by the collision with the atoms in the gas; another item of interference is the electric spark. We can certainly claim to have approximated the tracks of the particles. But so long as we must interfere with the rays in order to measure them, our photograph must always remain an approximation. This is a serious consideration that plays a role in every measurement to determine quantity. But a thing, apart from its measurement, has no meaning in physics.

The Heisenberg principle of indeterminism has aroused much speculation among physicists and also among the positivists who wish to equate scientific knowledge with the whole of certitude. Though the principle has been given a wide variety of different interpretations, it simply states that we cannot measure position and velocity simultaneously. This definition can be best explained and defended by an example. Suppose that we are measuring a