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The Unity and Diversity of Natural Science

ON THE QUESTION of where the study of nature should begin, Aristotle's teaching is clear and familiar. His first treatise on natural science, the *Physics,* tells us, at the very beginning, that the investigation of nature must

> start from the things which are more knowable and certain to us and proceed towards those which are clearer and more certain in themselves; for the same things are not "knowable relatively to us" and "knowable" absolutely. So in the present inquiry we must follow this method and advance from what is more obscure by nature, but more certain to us, towards what is more certain and more knowable by nature.—Now what is to us plain and obvious at first is rather confused wholes, the elements and principles of which become known to us later by analysis. Thus we must advance from [vague] generalities to particulars. For it is a [vague] whole that is more known to sense perception, and a generality is likewise a kind of whole, comprising many things within it, like parts. Much the same happens in relation of the name to the definition. A name, such as "circle," means vaguely a sort of whole: the definition analyses this whole into its parts [i.e. defining parts]. Similarly a child begins by calling all men "father," and all women "mother," but later on distinguishes each of them.[1]

Should the thought occur to us that modern science may have rendered this mode of procedure obsolete, just as it has invalidated much

[1] *Physics,* Bk. I, ch. 1, 184a17-184b14.

of Aristotle's cosmology, we shall find no support for our suspicion in one of the more advanced expositors of the scientific outlook, namely Lord Russell. Just last year, he wrote of a "prejudice" which he describes as "perhaps the most important in all my thinking."

> . . . This is concerned with method. My method invariably is to start from something vague but puzzling, something which seems indubitable but which I cannot express with any precision. I go through a process which is like that of first seeing something with the naked eye and then examining it through a microscope. I find that by fixity of attention divisions and distinctions appear where none at first was visible, just as through a microscope you can see the bacilli in impure water which without the microscope are not discernible. There are many who decry analysis, but it has seemed to me evident, as in the case of the impure water, that analysis gives new knowledge without destroying any of the previously existing knowledge. This applies not only to the structure of physical things, but quite as much to concepts. 'Knowledge,' for example, as commonly used is a very imprecise term covering a number of different things and a number of stages from certainty to slight probability.
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> It seems to me that philosophical investigation, as far as I have experience of it, starts from that curious and unsatisfactory state of mind in which one feels complete certainty without being able to say what one is certain of. The process that results from prolonged attention is just like that of watching an object approaching through a thick fog: at first it is only a vague darkness, but as it approaches articulations appear and one discovers that it is a man or a woman, or a horse or a cow or what not. It seems to me that those who object to analysis would wish us to be content with the initial dark blur. Belief in the above process is my strongest and most unshakable prejudice as regards the methods of philosophical investigation.[2]

Now, what can such a mode of procedure have to do with our question, which is where we ought to begin a study of nature? The method described means that we should begin with generalities which, though vague, are quite certain. Of course no intellect with a speculative vitality can rest in these generalities however reassuring in their certainty. The mind wants to know as much as it can about as much as there is to know. Knowledge, as we progress, must become more and more specific and detailed. The real question is, ought we to make some formal, radical, distinction between our first approach to nature, with its vague certainties, and the more particular knowledge acquired as we move forward?

It would be disastrous to fall back into the ancient confusion that sciences are distinguished according to degrees of generality. Not that we refuse all value to distinctions based upon degrees of generality. St. Thomas's own *Proemium* to the Physics distinguishes the various branches

[2] *My Philosophical Development* (New York, 1959) p. 133.

of natural science according to what is less and less universal, and natural science can hardly proceed without divisions based upon decreasing generality, if by generality is meant community of predication, as "animal" is more common than "man." Hence it is that Aristotle, in the first treatise of natural science, the *Physics,* studies mobile or changeable being in general. What he there establishes is meant to apply to every kind of change. First to absolute change, as when a man comes to be or dies; then, to the special kind of change called motion, such as walking, turning pale, or growing. Notice, however, that in the modern study of nature there is nothing that corresponds to the problems and discussions of the *Physics.* For instance, we accept some initial, nominal, definition of movement, infinity, place, time, etc., but we no longer ask just what are the realities which these words are intended to mean. In fact, many a modern author, in his attempt to arrive at a real definition of movement, will conclude that there is no such thing and reduce it to an illusion arising from a succession of immobile states. It would be easy enough to show how he reaches his curious conclusion, and how it is quite beside the point. But this is not my subject. All I mean to stress is that in fact modern researchers often fail to begin by analyzing vague generality first conveyed by the word "movement." Right from the start they want something exact, such as the way a movement is measured, in terms of place and time, with both these latter items left equally undefined except as to name; and movement, time, and place are soon replaced by symbolic constructions which some will interpret as substitutes more exact than the names—which in a sense they are. But symbols, however precise the rules for their use, may easily leave the basic issues as obscure as ever. What has been lost sight of is that the only way of achieving true success in such investigation is by deeper and deeper understanding of what was at first only vaguely known.

My high school textbook of physics—nearly forty years ago—began with *La dynamique céleste,* which could in some measure be held to correspond with the treatise *De Cœlo,* namely cosmology. The subject of the *De Cœlo* was mobility according to place, by means of which the universe itself is defined. The aim of the study was to discover laws governing the universe, an aim which is still that of physics today. Though local motion is the most common sort of change, it is of a special kind nonetheless. So by starting the study of nature with this kind of motion, a science must overlook what all kinds of change have in common. The mind is applying itself immediately to their differences and will soon be led to deny these. For example, the denial of these differences is implicit

in thinkers who believe that the ultimate explanation of whatever there is to be explained in nature will be a mathematico-physical one. Of course there is also an impressive number of eminent physicists who reject this over-simplification.

Aristotle's third treatise on nature is about change according to quality: *On Generation and Corruption*—the two terms of alteration. Although it is only in relatively familiar living creatures that these absolute terms of qualitative change are verified beyond a doubt, it may well be true that all natural things are subject to such alteration. At any rate, no exceptions are known for certain. Still, motion according to place obviously remains more universal than change of quality and the kind of coming to be or passing away attendant upon it. Allow me to call your attention to the fact that, in *On Generation and Corruption,* Aristotle pays chief attention to sensible qualities, such as hot and cold, wet and dry. For this reason, there are many who point out that his view of nature was essentially a qualitative one, whereas the modern one tends to be entirely quantitative.

Finally, in the fourth of these treatises, Aristotle applies himself to the kind of mobile being that changes according to quantity, in growth and decrement. This is the living being, which is surely a less common object in nature, no matter how much life there may be on as many other planets as you choose. Now, it is exceedingly important to notice that the Philosopher, in his treatise on living beings, should start, not by considering, first of all, living being in general, as he has taken mobile being in the *Physics,* but that he should begin with a study of the soul: *De Anima.* The reason is, as St. Thomas explains, that the investigation of living things is from the outset based upon a new kind of experience: the experience of being alive which we ourselves enjoy as we have sensations. If we abstracted from this experience, we could never arrive at any definitive reason for distinguishing the living from the non-living. Indeed some moderns already find themselves at this point. For them, swelling and growth have become the same thing; reproduction is perhaps mere copying; atoms are said to repair themselves, and the operations of mechanical computers are identified with thought. In other words, if we abstract from our inner experience of being alive, as distinguished from sheer external sense experience, thus excluding, as it were, all reflection upon sense experience, we will find ourselves surveying living things from a point of view which can never acknowledge even the most obviously living things to be alive. The unpredictable behavior of some

animals might always be attributed to our ignorance of the relevant data.

From the *De Anima,* which defines the principle of life and its differences in kind, we move on towards more concrete knowledge of the organic power of sensation and its object: *De Sensu et Sensato.* Experience of sensing, and reflection upon this experience (which we call "internal"), remain in the foreground, but we are now bent upon relating sensation to the physical tools which it implies and upon which it depends. Then follow the *Parva Naturalia: De Memoria et Reminiscentia, De Somno et Vigilia, De Juventute et Senectute, De Morte et Vita.* Notice that the latter two studies refer to states that are common to all familiar animals and even to all forms of life. In other words, within biology itself, we are following an order which in a sense is the reverse of that observed in proceeding from the generality of the *Physics* to reach biology. In the study of life we begin with confused knowledge, it is true; yet it is knowledge not of an integral whole, but of an integral part, namely, that by reason of which a living thing, primarily the animal, differs from a mere body. From this we progress gradually, with growing dependence upon external experience, toward more distinct knowledge of the part, of course, but also, and simultaneously, of the whole. For the study of that which makes a living thing to be alive must eventually entail the study of each of its organs, and of their ultimate coordination.

The first living beings to be considered in their totality are the animals. Such study will lead man into the jungle, sea, air, and back to the laboratory. The knowledge he amasses is first descriptive of the type recorded by Aristotle in the *De Historia Animalium.* Then he will want to know why the various kinds of animals, including man, should be built as they are and behave as they do. This is the subject of the *De Partibus Animalium.* In still further treatises the scientist must become even more concrete and apply himself to the particular way in which various animals come to be, reproduce and get around. I refer to the treatises *De Generatione, De Motu Animalium* and *De Progressione.* Aristotle, the Philosopher, desired to know why dogs run a little slantwise! The man whom in our day we call a philosopher is quite indifferent, if not averse, to this kind of knowledge. We should be reminded of what his great forerunner declared in the *De Partibus Animalium:*

> We now proceed to treat of animals, without omitting, to the best of our ability, any member of the kingdom, however lowly. For if some have no graces to charm the senses, yet even these, by disclosing to the mind the architectonic spirit that designed them, give immense pleasure

> to all who can trace links of causation, and especially to those who are naturally inclined to philosophy. Indeed, it would be strange if mimic representations of them were attractive, because they disclose the mimetic skill of the painter or sculptor, and the original realities themselves were not more interesting, to all at any rate who have eyes to discern the reasons that determined their formation. We therefore must not recoil with childish aversion from the examination of the humbler animals. Every realm of nature is marvellous: and as Heraclitus, when the strangers who came to visit him found him warming himself at the furnace in the kitchen and hesitated to go in, is reported to have bidden them not to be afraid to enter, as even in that kitchen divinities were present, so we should venture on the study of every kind of animal without distaste; for each and all will reveal to us something natural and something beautiful. Absence of haphazard and conduciveness of everything to an end are to be found in Nature's works in the highest degree, and the resultant end of her generations and combinations is a form of the beautiful.[3]

But let us return to our problem. When we move from the realm of the *Physics* into that study which today takes the place of the *De Cælo;* or from the *De Anima* to the *De Animalibus,* are we going from philosophy to science? Or, if the order were reversed, would we be going from science to philosophy? But can we in fact practice the one without the other? Relativity and quantum theory are often said to be scientific and not philosophical. Stated as a principle, this distinction puzzles me. I can see that Einstein's theory does not depend upon a definition of time of the type which Aristotle provides in his *Physics;* and that the ancient definition does not depend upon time as Einstein describes it. Yet both Einstein's theory and Aristotle's definition have to do with nature in some way or other. The point is: do these diverse ways relate to diverse purposes? To put it more exactly: do they divide the subject-term of the study of nature? It might be remarked that of course their purposes differ: in one case the aim is to know just what time is; in the other, to know what time it is, how to measure a length of it, or how to define simultaneity at a distance. The difference is plain, but does it oblige me to conclude that the time of mathematical physics has nothing to do with the time known and named before mathematical physics began? Let me refer again to the text we quoted from the *De Partibus Animalium:* it is a "thirst for philosophy" that sets one on to investigate sensible things in a fashion now called scientific as distinguished from the philosophic.

Yet Aristotle and St. Thomas themselves use language which seems to support a real distinction between philosophy and science, because

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[3] *On the Parts of Animals,* Bk. 1, ch. 5, 645a-25. Cf. *On the Heavens,* II, 12, 291b25.

they speak of "natural sciences" in the plural; so that, if one of these is natural philosophy, it would appear to be something other than the rest. Notice, however, how this plurality is explained:

> . . . One science can be subject to another in two ways. First, when the subject of one science is a species of the subject of the higher science; in this way the animal is a species of natural body, so that the science of animals is subordinate to natural science. There is subordination in another sense, when the subject of an inferior science is not a species of the higher one, but when the subject of the inferior science compares to that of the superior one as what is material to what is formal.[4]

The latter kind of subordination is called subalternation. An instance of this is the way the science of optics is subordinated to geometry.

But, if these two kinds of subordination be properly understood, it will become clear that, though they do give rise to distinguishable fields of study, they do not truly divide the subject of natural science. That the first kind does not have this effect is plain from the example: the study of animal is only an extension of the study of body. Let us see how the second also fails to generate an entirely new science.

Geometry, to take up our own example, is used in optics for the sake of manifesting sensible phenomena, not for the sake of furthering geometry, a science which constructs its own subject and has no more than a remote foundation in reality. Mathematics is not about nature, yet we use it to manifest nature; for mathematics, in this respect akin to logic, is about subjects and their properties that follow from our mode of understanding—*consequuntur ex modo intelligendi, sicut est abstractio mathematicorum et hujusmodi.*[5]

True, optics and harmonics are formally mathematical, since in them we apply to subjects of sense experience mathematical knowledge which, even when applied, remains mathematical.[6] Though only materially natural, the subject which we aim to reveal is nonetheless natural. For this very reason we call such sciences "more natural" than mathematical: *"because everything is named and specified by its terminus:* hence because the business of these sciences terminates in natural matter, even though

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[4] *In I Anal. Post.*, 1.5.

[5] *In I Sent.*, d. 2, q. 1, a.3.

[6] "Nam geometria considerat quidem de linea quae habet esse in materia sensibili, quae est linea naturalis: non tamen considerat de ea in quantum est in materia sensibili, secundum quod est naturalis, sed abstracte, ut dictum est. Sed perspectiva e converso accipit lineam abstractam *secundum quod est in consideratione mathematici,* et applicat eam ad materiam sensibilem; et sic determinat de ea non inquantum est mathematica, sed inquantum est physica." *In II Phy.*, 1. 5.

they proceed through mathematical principles, they are more natural than they are mathematical."[7]

Why should all the divisions of natural science be no more than material divisions, including even the distinction between the purely natural sciences and those which, though mainly natural, are formally mathematical? The reason is that sciences are formally distinct according to their modes of defining, and of these there are, generically,[8] only three, the natural, the mathematical, and the metaphysical. Whether it be man or rainbow that we describe or define, our description or definition must include sensible matter, and this is to define in the natural mode. The subjects of mathematics, however, are defined without sensible matter, though they would need it to exist outside the mind where they would cease to be mathematical. Finally, there are the definitions of metaphysics, namely, of subjects which are entirely separated or separable from sensible matter, although their real existence is not easy to establish. Any other mode of defining would have to be of non-sensible things with sensible matter, which is impossible except in a verbal way. Now, the whole point is that "sensible matter" is a generic and univocal term, like the "intelligible matter" of mathematics[9]—such as the continuity of a line or the units of a number. But "matter" is said analogically of "sensible" and "intelligible." Yet, unlike "sensible matter," "intelligible matter" gives rise to specifically distinct sciences not because of the specific differences, but by reason of different modes of defining, as can be seen in the radically distinct modes of construction. Metaphysical subjects are defined by *excluding* all matter, whether sensible or intelligible, and their definitions are in this sense negative, although the *definita* are most positive.

We must consider still another difficulty, one which is more obvious in our time, and that seems to justify the distinction between philosophy of nature and natural science. The ancients did not suspect the prodigiously fruitful role of fictions—"logical fictions," as Bertrand Russell calls them.

[7] *Ibid.*—It is true that physico-mathematical sciences are sometimes called *species scientiae mathematicae*. But this does not mean that they are a species of a genus in the way animal is a species of body. As St. Thomas explains: "Interdum tamen dicitur aliquid esse species alicujus generis propter hoc quod habet aliquid extraneum, ad quod applicatur generis ratio. . . . Et simili modo loquendi dicuntur astrologia et perspectiva species mathematicae, inquantum principia mathematica applicantur ad materiam naturalem." *Summa Theol.* I-II, 35, 8.

[8] The word "generically" is used because of mathematics which, when considered as science in the strict sense of this term, is twofold, namely arithmetic and geometry, each of which has its own mode of defining without sensible matter.

[9] *Cf.* my "Abstraction from Matter," in *Laval théologique et philosophique*, XIII (1957) 133-196; XVI (1960) 53-69.

Nor did Galileo or Newton, for the matter of that; a fact ironically brought out by Newton's famous *hypotheses non fingo.* (Newton actually contrived most fruitful fictions, though he failed to realize that they were fictions.) The contemporary mathematical physicist knows that he can probe into the world of nature only by means of mental constructions suggested in part by experience, in part by mathematics. They are fictions in the strict sense of this term, whose power we must not underrate. The atom, for instance, is largely a logical fiction. If you have any doubts, look at what has happened to atoms since Dalton's days. (I say "largely," for in physics the mental constructs must have some foundation in experience and experiment, else they could hardly lead to further knowledge of nature.)

Let us look a bit more closely into this subject. Is the mode of defining in mathematical physics today still the same as in earlier times—namely, with sensible matter? Yes and no. First of all, the definitions of mathematical physics are no longer definitions in the strict sense of this term. They are not even nominal. The astronomer cannot make much headway with nominal definitions of "sun" or "moon," which may be verified by pointing to the sun or the moon. He has his own mode of defining, and it is not even nominal, it is symbolic, although he uses words in describing measurement and experiment. The raw materials of his type of knowledge are already the result of measurement and experiment, gathered into and expressed by measure-numbers that are symbols.

Now there is a curious fact about these symbols: they must in the end refer to a very particular concrete object found near the capital of France, the product of a convention, namely, the meter, or some similar device. For "meter" does not mean simply "measure," or "standard of length," though the word comes from the Greek *metron,* which means, universally, "that by means of which the quantity of a thing is first made known." The mathematical physicist can get nowhere with such a definition. *His* "definition" of the meter is "the distance between two lines on a certain platinum-iridium bar kept at the International Bureau of Weights in Paris, when this bar is at 0° C. or 32° F. Copies of this bar are kept elsewhere."

"Meter," in physics, is the name we have given to a certain physical object of our own making. It should be understood as a proper name, like "Oscar." We have fair copies of the meter, in a laboratory or dry goods shop, but the authentic one, the real Oscar, is in Paris. Now this is an individual, singular thing from which, so long as the convention holds, we must not deviate. It turns up in all other measurements—even in the most

unexpected of these, namely, in the definition of temperature which enters into the "definition" of the meter. For the platinum-iridium bar is called a meter-long when its temperature is 0° C., and the mercury column of our thermometer has a scale which is a graduated length. If the definition of meter were intended as an authentic one, like that we gave of "measure," it would be circular. It is a "definition" only in the original sense of "de-limiting," and thus "setting apart."

One might object that there ought to be something universal about the meter, since there are many copies of the one kept in Paris, and that "meter" can be said of each. But the objection ignores the real issue. For no metal bar anywhere is a meter except to the degree that it is a fair copy of the original one in Paris, and the Parisian one cannot be predicated of any but itself. It is true that if the Paris meter were destroyed, we would construct another, but our convention would still hang upon an individual object.

The mathematical physicist is no doubt after universal knowledge, but the essential thing is that he no longer pretends to achieve it. He can scarcely dare, when his entire science must rely upon an individual object. Much the same is true of all the natural sciences as they advance towards greater concretion. Our definition of man as a "rational animal" is safe enough, but this tells us nothing about the anatomy and physiology that characterize man. To acquire knowledge of this kind we must perform experiments upon individuals, and further knowledge will depend upon these. Now a knowledge which continues to depend upon individual things may hardly be called "science" in Aristotle's sense, for the simple reason that individual things are never sufficiently grasped. By *épistèmè* Aristotle meant knowledge about a universal subject, acquired by demonstration from first, self-evident, and proper principles. Even to him there was not much of it outside of logic and mathematics. But if it be knowledge of the physical world that we seek, we will soon be launched on a sea of provisional generalizations, universals *ut nunc,* i.e., for the time being, and of hypotheses to be improved upon by further hypotheses. Though we move on in great strides, nothing final can ever come into sight.

We are sometimes told that this precarious, provisional character of even the most exact branch of natural science, mathematical physics, must not be overstressed. And the reason offered is that we achieve undeniable results. The results may be indeed most practical, but does this require that the theoretical knowledge which led to their success be speculatively true? We can launch artificial satellites on the basis of Newtonian physics, but does this prove that such physical theory is true? Practical

success is always a sign that we are on the right track towards speculative truth, but to move towards a term and to have reached it are not quite the same thing. Dalton's atoms, conceived as billiard balls, only much smaller, served their purpose and were nearer the truth than those of Democritus; but they were not the last word on the subject, nor are the atoms of today. Just because we can set down the word "atom" does not mean that there are atoms in the way that there are apples. Atoms are not atoms in the way apples are apples. As Heisenberg puts it: "we cannot speak about the atoms in ordinary language."

Now, all this faces us no doubt with a deep enough cleavage between diverse modes of knowing the things of nature. But does this cleavage restrict natural philosophy to our initial gropings among vague generalities, and hold experimental science to mere concrete investigation? What we are agreeing to call philosophy of nature is experimental too, though not quite after the manner of mathematical physics nor even of advanced biology. I pointed out long ago that in the study of nature we must distinguish between strictly scientific knowledge (in Aristotle's sense) and that which is called dialectical, as providing no more than opinion. Now, opinions are still enunciated in words, and are in fact true or false if it be speculative knowledge that we mean to express. Notice, however, that an opinion is not a fiction in the strict sense of this term. It is, at bottom, an inquisitive proposition. The opinion that "the world is eternal" still leaves open the question whether the world really is or has to be eternal. We can unfold what we mean by "world" and by "eternal," but can we in truth say the latter of the former? The notions of "world" and "eternal," though vague, have a relatively stable meaning. What we are questioning is not their meaning, of course, but their connection in a proposition. Is such a proposition necessary? Is the eternity of the world a fact?

But in mathematical physics, when words are used to describe, not how things are in fact, but merely how a certain symbolic construction has been laid down, e.g., that of the atom, we must be aware that, unlike the terms used in a statement about nature, the symbols, the construction, and the names we choose to employ for the purpose of communication do not have a stable meaning. The only stable meaning the word "atom" ever had was that of "indivisible." In other words, we are now entitled to question not merely the connection of the terms, but the very terms themselves. At any rate, these are utterly provisional, whereas what "world" or "eternal" stand for are not.

It should now be plain that our study of nature can proceed on three different levels: that of science, that of opinion, and that of terms that are themselves provisional—whose meanings are accordingly unstable. There is no doubt that in point of certitude there are radical distinctions between these various modes of investigating nature: between vague knowledge that is certain and definitive, such as knowledge of what the word "man" stands for; knowledge that is tentative, of the kind we have in dialectical propositions; and knowledge that is both tentative and known to be provisional, provisional even as to the very terms we use to express it. The latter kind is nothing short of paradoxical, since greater exactness is paid for by increasing instability. These distinctions are quite relevant, but our great question is, do they divide the purpose of the study of nature? Will the three different methods require that science be formally divided in accordance with them? Do these provide us with different subject-terms?

It may be useful to consider two extreme positions on this question. Some hold that if there is to be a natural philosophy it must remain confined to certain generalities, such as the conditions of absolute becoming, the definitions of motion, infinity, place, time, etc.; and that when we carry our investigations further, we then practice experimental science, as in seeking to know what the speed of light is. Others, again, believe that natural philosophy presupposes the experimental sciences, and is no more than a reflection on their method and on their present achievements and implications as compared to those of earlier science. Natural philosophy and philosophy of science would be much the same.

Both of these conceptions are partly true, for there is no doubt that we must examine first of all the things we first name, and these are vague generalities. They are, in a sense, the most important, and to neglect them will eventually spell disaster. The doctrine of prime matter, for instance, is essential to save the unity of the human individual. For if we held that a man is no more than an accidental superstructure made up of electrical charges, a human person would be no more of an individual than an individual pile of bricks.

But is it the sole function of the natural philosopher to be stubborn about the validity of such problems, about their possible and even definitive solutions? Does he cease to be a philosopher when he asks more concretely what a man is? When he asks what is the anatomy and physiology of the human brain? Or what are its chemical components? Why should the mind interrogating nature rest in vague generalities, no matter how important and how certain these may be? Is there anything unworthy

about investigating man's organic constitution, or the activities of slug-worms? It is of course true that no single individual can in our time ever hope to know the whole of even a single ramification of natural science, such as astronomy and botany, nor even list the unlimited number of questions men may eventually learn to ask about a relatively narrow domain of nature. Yet no matter how general or how particular, how certain or provisory, knowledge about nature will always be derived from, and must return to, experience, external or internal. In each and every case, if the knowledge is to be of nature, the descriptions and definitions, no matter of what kind, must in the end include sensible matter. It does not seem possible therefore to set a rigid frontier between philosophy of nature and science of nature.

The second opinion we described is likewise partly true. For if philosophy is to deserve its name, it will never confine itself to one narrow domain of nature or become indifferent to findings achieved by a particular method of research. A man may be a skillful investigator, but he will never be master of his science until he knows just what it is that he knows, the status of his own mind with regard to his particular subject; and until he comes to realize, if only vaguely, how much there is that he does not know. But the great shortcoming of this opinion, that philosophy of nature must be simply philosophy of science, is its inevitable failure to pay explicit attention to the vague generalities with which all thinking about reality must begin, and to which all later knowledge must be related. To rest in vague generalities is unsatisfactory to the inquisitive mind, but to rest in "man is a swarm of atoms" is no less reprehensible, for the simple reason that intelligence must demand a connection between this statement and the knowledge we already have of man, as expressed in ordinary language; when we ask what man is, for example, or what he is made of, and how. Heisenberg puts it this way: "Even for the physicist the description in plain language [as distinguished from that of theoretical physics] will be a criterion of the degree of understanding that has been reached." [10]

A wholly legitimate question may now be raised: does not our very criticism of these two opinions imply a distinction between natural philosophy and natural science? Does not our criticism allow that a man may be a skillful scientist without any desire to reflect upon what he has achieved, and to see how this relates to his earlier knowledge? I grant that there do exist skillful scientists who see no point in "philosophical

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[10] *Physics and Philosophy,* (New York, 1958), p. 168.

questions," but it is equally true that the most eminent "scientists" are without exception very much concerned with philosophical questions. And so I suggest that the existence of these two types of scientists can scarcely oblige us to divide the study of nature into two ideally distinct endeavors. To my mind, the distinction is a purely contingent one. The skillful scientist who has no further preoccupation is really only a tool; he is to the true man of science what a laboratory technician is to the physicist or biologist whom he serves. If he be called a scientist, it is only in virtue of a change in the imposition of the term "science," and if one explained this to him, he would most probably object to being called a scientist in this new and exclusive sense.

I have heard a skillful biochemist maintain that philosophical questions are impossibly difficult, if not wholly inane; whereas the scientist's problems can become real and meaningful when he can reduce them to the simplest kind of questions. These questions he assumed to be entirely direct and clear—e.g., what is the chemical structure of a protein molecule?—so much so that a philosopher would consider them unworthy of his attention. Such a philosopher would be not worthy of the name. If a single man cannot engage upon specialized research in so many diverse fields, if the philosopher cannot hope to be much of a scientist, nor the scientist to be much of a philosopher, surely this is a state of things which both ought deeply to regret.

As already suggested, there is no doubt that in the study of nature we are faced with two very different kinds of questions. Let me use time as an example. The name "time" is in common use, and used in a significant way. So we do have some vague knowledge of time, else it would not occur to us to ask what time is, as in Book IV of the *Physics*. The answer is that time is a measure of movement; more precisely, "the number of movement according to the before and after of movement." Now this requires that time itself be a movement, since a measure must be homogeneous with the measured.

But it is not merely as a movement that time is the measure of movement. It will have the nature of measure by reason of its regularity and speed. And to we are led to the further question: where in nature is this movement to be found? Aristotle found it in the outer sphere of the universe. Has that earlier definition of time broken down along with the structure of the universe as he conceived it to be? The article on *Time, its measurement,* in the *Encyclopedia Britannica,* tells us that time is still defined in terms of speed and regularity, man is still in search of this true constant of speed. Where to search for it is a question specifically pertain-

ing to mathematical physics. I fail to see, however, how uncertainty as to where time is to be found can affect its original definition.

The late Hermann Weyl, an outstanding mathematician, declared that "the first step in explaining relativity theory must always consist in shattering the dogmatic belief in the temporal terms past, present, future. You cannot apply mathematics as long as words becloud reality."[11] There is a sense in which this is so. But will his statement be true if interpreted to mean that the time of mathematical physics has nothing at all to do with time as first named? Weyl was too good a philosopher to adhere consistently to such an interpretation of his words.

There is a great deal of equivocation about the relation of the familiar world to the scientific one. Some writers seem to argue, either that the one has nothing to do with the other, or that only the "scientific world" is true. According to Max Born, and I think he is right, Eddington was prone to overstress, especially in his analogies, the role of mental construction in physics and did not sufficiently emphasize, as Einstein had, the fact that such construction is utterly empty unless related to experience as the first and ultimate norm. The essential point is that the familiar elephant and the scientific one are not in different worlds: the scientific one does not banish the one who slides down the grassy hillside. If, for the solution of a given problem, the elephant can be replaced by two tons of something else, this only goes to show that the problem was not about the elephant, but about two tons of whatever you choose. The elephant may have disappeared from our consideration; he has not disappeared from reality.

Eddington made a good point, of course. Still, our indebtedness to him should not allow us to forget that whatever slides down his grassy slope will be a thing of some kind or another, but decidedly not a pointer-reading. There is no reason why physics should deprive zoology of its elephants, even though some biologists seem to believe that eventually zoology must so surrender them—despite protests from ranking physicists, who would not know what to do with elephants as such.

Professor Max Born has stated our case well:

> Physicists form their notions through the interpretation of experiments. This method may rightly be called Natural Philosophy, a word still used for physics at the Scottish universities. In this sense I shall attempt to investigate the concepts of cause and chance in these lectures. My material will be taken mainly from physics, but I shall try to regard it with the attitude of the philosopher, and I hope that the results obtained will be

[11] "The Mathematical Way of Thinking," *Science*, XCII (1940), 439.

> of use wherever the concepts of cause and chance are applied. I know that such an attempt will not find favor with some philosophers, who maintain that science teaches only a narrow aspect of the world, and one which is of no great importance to man's mind. It is true that many scientists are not philosophically minded and have hitherto shown much skill and ingenuity but little wisdom. I need hardly to enlarge on this subject. The practical applications of science have given us the means of a fuller and richer life, but also the means of destruction and devastation on a vast scale. Wise men would have considered the consequences of their activities before starting on them; scientists have failed to do so, and only recently have they become conscious of their responsibilities to society. They have gained prestige as men of action, but they have lost credit as philosophers.[12]

Born seems to be understanding wisdom in a practical, moral sense. But I think he has more in mind than this. Practical wisdom is one that follows upon awareness that man, being what he is, cannot be looked upon indifferently by the physicist, for the simple reason that the true physicist must be a philosopher who realizes the limitations of his particular branch of science. Belief that his part is the whole, or that it is a self-contained whole, would be preposterously unscientific. What Born means, as I understand it, is that, no matter how skillful or ingenious, no one can be a true scientist without being a philosopher. Nor does a man bear witness to a *temperamentum philosophicum* if he does not realize that scientific investigations, taken in the narrower sense we have described, help the mind to escape from ignorance and, as Aristotle said, "provide immense pleasure to all who can trace links of causation, and are inclined to philosophy." Indifference to the phenomena of sun and moon, to bugs and elephants, proves the absence of philosophic temperament.

Why, then, has the wholly artificial distinction between philosophy and science been so readily accepted? It has in some measure been forced upon us by inevitable specialisation, or, to put it another way, by the limitations of the single brain. But these limitations are not to be projected upon natural science and its subject. The fact that no mathematician now knows more than part of mathematics ought hardly be taken to mean that the whole subject of the science is confined to the part that he knows. The knowability of a subject should not be restricted to and identified with what a given man may actually know of it with some exactness. This is another way of saying that what is knowable as to us must not be confused with what is knowable in itself.

The unscientific limitation just mentioned finds ample illustration in the history of science. Let me quote an example of what I here intend.

[12] *Natural Philosophy of Cause and Chance* (Oxford, 1949) pp. 1-20.

It is again from Born. He has in mind Laplace's idea of causality, namely, that the future is wholly predetermined in the past. "An unrestricted belief in this type of causality leads necessarily to the idea that the world is an automaton of which we ourselves are only little cogwheels. This means materialistic determinism." [13] Such a generalisation, reared upon a still primitive astronomy, was unscientific, if only because it ignored human responsibility. It was no doubt an "idée claire et distincte," yet, like most such ideas, utterly lacking in wisdom, if only because it clashed with a hard, though intangible, fact of experience, just as obvious as the succession of night and day. Hypotheses of this type are those of a scientist gone mad or, if you wish, of a bad philosopher. Are we to conclude from this that it is precisely the business of the philosopher, as distinguished from that of the scientist, to defend things such as human freedom, and to show that universal determinism is an unsound hypothesis? I should say that the wise scientist too, should know as much, since he does and must philosophize.

There is, nonetheless, a historical case for the distinction we reject in principle. The man who putters in a laboratory may not have time to concentrate upon the outcome of his convenient generalisations. Yet there ought to be some one able to warn us of logical consequences that clash with the whole of experience. No one may possess a head big enough to contain all the knowledge of nature now available; but general, though vague, knowledge, we do have, knowledge which can be explored up to a point without moving on to further concretion. To call attention to the extreme relevance of our first and vague knowledge of reality, the sort that we express in ordinary language, may be the self-imposed task of some people, whom we call philosophers. Still, my contention is that if, in this restriction of their work, they see anything more than a limitation forced upon them by the shortcomings of the human brain, they are projecting this limitation upon nature as if real things stood in different worlds according as they are seen by philosopher or scientist. Small wonder if minds convinced of such a doctrine want to reduce all philosophy to a hopeless metaphysics in the empty air of unqualified verbal "being." So far as I am concerned, I refuse to renounce myself for a mere swarm of electrical charges, no matter how much I may stand in need of them and know that I cannot exist without them.

The need to bring out connections between our "common concepts," expressed by so-called "natural language," and the mathematical

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[13] Born, *op. cit.*, p. 3.

scheme of theoretical physics has been felicitously stressed by Werner Heisenberg in his Gifford Lectures.[14] Remember the passage already quoted: "Even for the physicist the description in plain language will be a criterion of the degree of understanding that has been reached." If the physicist's knowledge were believed to be quite divorced from common concepts and ordinary language, then we would of course have the kind of scientist who is not a philosopher. Such a scientist, I repeat, would not even be a true scientist, but a mere tool.

Here is that relevant passage from Heisenberg's Gifford Lectures:

> . . . One of the most important features of the development and the analysis of modern physics is the experience that the concepts of natural language, vaguely defined as they are, seem to be more stable in the expression of knowledge than the precise terms of scientific language, derived as an idealization from only limited groups of phenomena. This is in fact not surprising since the concepts of natural language are formed by the immediate connection with reality; they represent reality. It is true that they are not very well defined and may therefore also undergo changes in the course of the centuries, just as reality itself did, but they never lose the immediate connection with reality. On the other hand, the scientific concepts are idealizations; they are derived from experience obtained by refined experimental tools, and are precisely defined through axioms and definitions. Only through these precise definitions is it possible to connect the concepts with a mathematical scheme and to derive mathematically the infinite variety of possible phenomena in this field. But through this process of idealization and precise definition the immediate connection with reality is lost. The concepts still correspond very closely to reality in that part of nature which had been the object of the research. But the correspondence may be lost in other parts containing other groups of phenomena.
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> Keeping in mind the intrinsic stability of the concepts of natural language in the process of scientific development, one sees that—after the experience of modern physics—our attitude toward concepts like mind or the human soul or life or God will be different from that of the nineteenth century, because these concepts belong to the natural language

[14] By "natural language" Prof. Heisenberg does not mean a language that is natural to us as our organs of speech are natural, as if nature provided us with a language in the way that she produces feet and brain. Unless we call the grunts and groans of man or beast "language," this term refers to artifacts that signify by convention. Using ordinary language we should always be able to refer its words back to common knowledge of things first known, a knowledge which may lead us to further knowledge of things, requiring either new impositions upon words already in use, or even, simply, a new word. An example of a new imposition would be the word "soul," which first meant breeze or breath; an instance of a new word is "God"—no matter what its etymological origin—for God can be known only at the term of a discourse, and once known, we impose the name as entirely proper to Him. I do not mean that in doing so we spell out a new word. The point is that in virtue of the imposition the name now has a single meaning incommunicable to anything else, except by metaphor.

> and have therefore immediate connection with reality. It is true that we will also realize that these concepts are not well defined in the scientific sense and that their application may lead to various contradictions, for the time being we may have to take the concepts, unanalyzed as they are; but still we know that they touch reality. It may be useful in this connection to remember that even in the most precise part of science, in mathematics, we cannot avoid using concepts that involve contradictions. For instance, it is well known that the concept of infinity leads to contradictions that have been analyzed, but it would be practically impossible to construct the main parts of mathematics without this concept.
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> The general trend of human thinking in the nineteenth century had been toward an increasing confidence in the scientific method and in precise rational terms, and had led to a general skepticism with regard to those concepts of natural language which do not fit into the closed frame of scientific thought — for instance, those of religion. Modern physics has in many ways increased this skepticism; but it has at the same time turned it against the overestimation of precise scientific concepts, against a too-optimistic view on progress in general, and finally against skepticism itself. The skepticism against precise scientific concepts does not mean that there should be a definite limitation for the application of rational thinking. On the contrary, one may say that the human ability to understand may be in a certain sense unlimited. But the existing scientific concepts cover always only a very limited part of reality, and the other part that has not yet been understood is infinite. Whenever we proceed from the known into the unknown we may hope to understand, but we may have to learn at the same time a new meaning of the word "understanding." We know that any understanding must be based finally upon the natural language because it is only there that we can be certain to touch reality, and hence we must be skeptical about any skepticism with regard to this natural language and its essential concepts. Therefore, we may use these concepts as they have been used at all times. In this way modern physics has perhaps opened the door to a wider outlook on the relation between the human mind and reality.[15]

Heisenberg has made our point. He has described for us the full meaning of natural philosophy. Having started with the concepts of natural language, as we move on into the realm of symbolic construction controlled by the test of experience, we must be constantly ready to sweep into reverse, as it were, lest contact with reality be lost. In doing so we will use ordinary language, whose concepts appear more stable than the precise terms of "scientific" knowledge. If we keep the total aim of natural science in view, symbolic terms are inadequate: to isolate them from the concepts of natural language is to divorce them from nature and therefore from natural science.

Bertrand Russell, in *Human Knowledge,* conveyed the same idea, though he seems to forget it when he declares 'Mr. Smith' to be no more

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[15] *Op. cit.,* pp. 200 - 201.

than a collective name for a mere bundle of occurrences. Here is the passage in question:

> All nominal definitions, if pushed back far enough, must lead ultimately to terms having only ostensive definitions, and in the case of an empirical science the empirical terms must depend upon terms of which the ostensive definition is given in perception. The Astronomer's sun, for instance, is very different from what we see, but it must have a definition derived from the ostensive definition of the word 'sun' which we learnt in childhood. Thus an empirical interpretation of a set of axioms, when complete, must always involve the use of terms which have an ostensive definition derived from sensible experience. It will not, of course, contain *only* such terms, for there will always be logical terms; but it is the presence of terms derived from experience that makes an interpretation empirical.
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> The question of interpretation has been unduly neglected. So long as we remain in the region of mathematical formulae, everything appears precise, but when we seek to interpret them it turns out that the precision is partly illusory. Until this matter has been cleared up, we cannot tell with any exactitude what any given science is asserting.[16]

There is no doubt that our view is not popular among contemporary scholastics. It appears so much more simple to have a neat set of theses called philosophy of nature, and to relegate more concrete investigations to the "scientists." But such a distinction is a purely pragmatic one, and merely reflects the impossibility for an individual to work in all the fields of this one subject, natural science.

The bewildering progress of natural science reveals not only the bottomless depths of nature and the ineffable variety of nature's works; it shows, at the same time, the unexpected limitations of any human mind, and the devious modes of knowing it must resort to, even in the study of things immediately around us. Still, to enquire what any object of nature is, and to pursue the enquiry down to the last detail, is surely a pursuit which deserves to be called philosophy. To answer such a question, all the branches of natural science should be brought into play, and each of these remains open to infinity. At least this much we know.

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[16] *Human Knowledge* (London, 1948), p. 258.