Michael Heller

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Appendices and Biographical Notes
by Małgorzata Szczerbińska-Polak

Translated by Kenneth W. Kemp &
Zuzanna Maślanka Kieroń

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Prof. Michael Heller
Copernicus Center
for Interdisciplinary Studies
Krakow
Poland
mheller@wsd.tarnow.pl

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Preface

The dominant view nowadays is that the philosophy of nature no longer exists. That branch of philosophy died out with the emergence of the modern empirical sciences. Its domain of inquiry was divided among the various particular sciences. Admittedly, there are still some philosophers who try to cultivate a philosophy of nature, but when one takes a closer look at their work it turns out that most of their effort is devoted to defining what exactly the philosophy of nature is supposed to study. The philosophy of nature as traditionally understood only prepared the ground for the future natural sciences and at their emergence lost its reason for being. Does that mean the elimination of philosophy from science? Not at all. In the first place, the very existence of science is a fact which requires philosophical reflection. That task was taken up by the philosophy of science. That branch of philosophy is flourishing and, just as happens with any respectable science, has many schools and specializations—from research into the kind of rationality represented by various sciences and the logic of the development of scientific theories, through analysis of the methods used by various sciences, to specialized analytic research into those aspects of scientific theories which the sciences themselves cannot handle.

Does that exhaust the tasks which philosophy must fulfill in relation to science? In answering that question, let us appeal to history. Above all, the statement that first there was the philosophy of nature and then the natural sciences arose and liquidated the place of philosophy in science is a crude oversimplification of the historical process. The natural sciences did not arise on the ruins of the philosophy of nature. They existed in parallel to it, though they were not always explicitly separated from it. It is sufficient to name the Greek sciences: astronomy, optics, acoustics, statics, not to mention geometry. One can only speak of a period of the domination of the philosophy of nature over the sciences until the beginning of the modern period, after which one must speak of the period of the domination of the sciences. The transition between those two periods was a continuous transition, although one rich in dramatic tensions. Notice how many typically philosophical problems were found in the spheres of interest of various scientific theories. The problems of time, space, and causality will serve as typical examples. Right down to our own day they are thought of as "great problems of philosophy" though at the same time all the fundamental theories of physics have much to say on these topics.

It is of course true that when some problem migrates from philosophy to the empirical sciences, it thereby changes its significance. We know that context is just as important as the "internal" connections between concepts. What is more, the problems and concepts transformed by the migration from philosophy to the sciences often come back for further philosophical deliberation, in that way thickening the connections between the two realms of knowledge.

The strengthening of that connection creates an interesting field of investigation. I have called it "philosophy in science," no doubt a summary expression and one which includes only some aspects of the phenomena which interests us here, but I hope that the entire book will constitute a justification for it. As I have already noted, the history of science itself bears witness to the presence in science of philosophical threads and it is for that reason that I have to write this book from a philosophical point of view.

That does not mean that the study of philosophy in science has to limit itself to purely historical considerations; it means only that historical considerations seem to be an indispensable element of a strategy which would allow us to see the philosophical significance of the sciences. In my opinion, a thorough knowledge of at least the most important trends which have appeared in the history of philosophy and science is a necessary condition of a responsible research program in the area of contemporary philosophico-scientific problems, and at the same time is an indispensable minimum of knowledge for the researcher working in other areas of philosophy.

I borrowed the idea of developing a series of lectures around the most important figures and themes from the history of place of philosophy in science from Professor Jean Ladrière, who gave such a series of lectures at the Institut Supérieur de Philosophie of the University of Louvain in 1982–1983. The unpublished notes from those lectures, made available in typescript through the kindness of Professor Ladrière, were of invaluable assistance to me.[1] The many references to Professor Ladrière's notes in the text of this book indicate my debt to him only partially. However, my own series of lectures is not a copy of the lectures given in Louvain. Professor Ladrière concentrated his attention principally on one problem, namely, on the relation of physics to metaphysics in the most important systems of the philosophy of nature. That is indeed one of the key problems, but I decided to go beyond that problem, and to undertake a more comprehensive discussion of the particular systems. As a result, the more focused formulation of Professor Ladrière has, in my book, become a more general series of lectures. That has manifested itself also in the method of the lectures.

Professor Ladrière limited himself to a discussion of the relation between physics and metaphysics in Aristotle, Descartes, Leibniz, Kant, and Whitehead. I have supplemented that account with a look at Plato, Newton, Popper and the so-called Romantic philosophy of nature. I also added a chapter on Aristotle's treatise *On the Heavens* and a chapter discussing the philosophical themes in contemporary

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[1] J. Ladrière, *Physique et Métaphysique*, the text of lectures read at the Catholic University of Louvain in 1982–1983.

science. A short chapter on the Ionic philosophers of nature and a slightly longer chapter as a kind of summary discussion supplement the whole. The reasons for my additions are as follows:

Many problems later treated by nearly all the great systems of the philosophy of nature come from the Presocratics, so it necessary to begin with them. Since all of Western philosophy is only a footnote to Plato (Whitehead), it is not possible to leave him out of a course of lectures; all the more since contemporary theoretical physics seems in many cases—more or less consciously—to refer precisely to Plato. Textbooks in the history of philosophy do not usually devote very much space to the philosophical views of Newton. Even if it is true that that thinker does not belong among the brightest stars in philosophical firmament (which is a matter of debate), the classical mechanics which he created had such a great influence on entire generations of philosophers, that one must give him a prominent place in any discussion of philosophy in science. As for Popper, one can of course have greater doubts, but from the point of view of the twenty-first century, it is already clear that his views have become an important achievement of the most recent philosophy.

I made a choice of themes with a view to their importance for philosophy in science. The single exception is the Romantic philosophy of nature. It is included in this book as an example (unfortunately, one among many in history) of unfruitful lines of inquiry. Because the field of the philosophy of nature is a great temptation for overly impatient minds, I thought it would be appropriate, at least in one case, to show where intuitions lead when insufficiently controlled by the rigors of logic.

I also added a chapter dedicated to a discussion of the philosophical significance of theories of contemporary physics. Over the years, it has become even more obvious that the natural sciences are not only taking up many themes which traditionally belonged to the philosophy of nature, but are also posing entirely new problems which require philosophical analysis. What is more, the influence of the natural sciences on philosophical thinking about the world is currently much greater than the influence of any one thinker.

One should not, of course, think of the present book as a comprehensive account of the history of the philosophy in science; it is only *selected problems*, although selected with a rather keen partiality for those which I saw as more important. The approach which I take in this series of lectures (for thus can one characterize the literary genre of this work), does not limit itself to looking "from the inside" of any concrete philosophical system; it is an attempt—by means of a history of the most important philosophical views—to identify authentically philosophical themes in the questions raised by the contemporary natural sciences. The identification of those themes is not yet their philosophical elaboration. That is a task that still awaits its author.

One can see the idea of philosophy in science as a contemporary version of the old philosophy of nature. For that reason, I will sometimes use those terms interchangeably. One can interpret that as a bow to tradition. Science by its very nature is avant-garde, but one of its methods in the conquest of new terrain is respect for tradition.

The present translation is based on the second Polish edition of this book (under a different title; the title of the previous edition was *The Philosophy of the World*) has been significantly expanded. It became possible thanks to the collaboration of Małgorzata Szczerbińska-Polak, who wrote all the Appendices and biographies. For that, I offer my sincere thanks. I also wish to express my sincere thanks to my translators, Professor Kenneth W. Kemp and Mrs. Zuzanna Maślanka-Kieroń. If it is true that every translator is a betrayer (*traduttore—traditore*), then it applies to my translators in the most minimal possible sense.

Contents

Chapter 1
The First Task of the Philosophy of Nature—The Problem of Elementarity

European philosophy began with a philosophy of nature. At the turn of the sixth centuries BC, on the Ionian coast of Asia Minor, and then in Magna Graecia and Sicily, some dozen or so thinkers dared to try to understand the world using only their own powers, without recourse to religious beliefs. The attempt exceeded all expectations: not with respect to success in understanding, but with respect to a certain kind of chain reaction that could not be stopped. Thus began one of the greatest of human adventures—the process of coming to understand the world by means of thought and experience.

The Greeks preserved their fascination with the order and harmony reigning in nature by extending the word *cosmos*[1] to mean the whole universe. Unusual harmony can also be found in the structure of living organisms. So, there is nothing surprising in the fact that the Greeks felt the world to be rather an organism than anything else. One should then explain the "functioning of the world" in the same way that one explains the functioning of organisms. It is no coincidence that philosophers of nature have sometimes been called physiologists.

The desire to decompose a functioning whole into its simplest parts is almost a reflex. We will understand the mode of action when we find out what is "at the bottom." That is how the physiologists responded. "The property of being most elementary of all would seem to belong to the first thing from which they are produced by combination."[2] Shortly afterwards, the technical term *arche* arose in place of the phrase "most elementary." In ordinary language, that term meant a beginning in the temporal sense (e.g., the beginning of the day); in philosophy it acquired the meaning of principle or material, but *the most basic.*

The first physiologists' answers to the question of *arche* were based on the naïve generalization of simple observations: heat, water and air are necessary for life, so the principle of nature is fire (Heraclitus of Ephesus), water (Thales of Miletus) or air (Anaximenes). But the Greeks very quickly made the transition from "crude observations" to attempts to capture the unobservable factor which

[1] Initially, the Greek word "cosmos" meant "beautiful, ornate" (compare the English *cosmetics*).

[2] Aristotle, *Metaphysics* I.8, 988b, trans. W. D. Ross, in Richard McKeon, ed., *The Basic Works of Aristotle* (New York: Random House, 1941).

would explain “that which is seen.” Such an analysis was made by Anaximander. According to him, *arche* must have the property of *unlimitedness*—because everything comes from it, and *undeterminedness*—because it gives rise to various kinds of being. A good terminology becomes an important element in philosophical inquiry: to denominate his *arche* Anaximander used the Greek term *apeiron*—boundlessness.

Once begun, the process quickly made progress. Applying the terminology of the Ionian philosophers of nature, one can say that for the Pythagoreans, *arche*, as an expression of cosmic proportion (i.e., harmony) was number, while for the atomists (Leucippus, Democritus, and later Lucretius)—*atoms* (i.e., indivisible components of matter). The Pythagoreans ascended to the heights of abstraction, opening the road of the sciences of nature to mathematics; the atomists chose to descend “into the depths.” Neither one nor the other stopped with the immediate testimony of the senses, but both searched for factors “detectable by thought,” which would make comprehensible that of which the experience of the senses speaks.

Principles of the world according to the greek philosophers

Thales	Water
Anaximander	*Apeiron*
Anaximenes	Air
Heraclitus	Fire
The Pythagoreans	Number
The Atomists	Atoms

* * *

The philosophy of nature began the history of European philosophy. What did it give to human thought? Above all, it taught man to rely on the power of his mind. Even if the answer is not obvious, it is worth it to put the question. *The situation of the question* is the point of departure for philosophy. It is necessary to measure one’s ability to answer questions with the aid of natural human equipment—thought and the testimony of the senses. The Ionian philosophers of nature made the first move towards *criticism and self-criticism*. These are two necessary conditions of philosophical integrity. Criticism creates the situation of the question, self-criticism does not allow one to accept just any answer. The search for the answer will with time take an ever more organized form. The first philosophers of nature originated the two perhaps most important elements of the strategy of philosophical research; namely:

1. *Terminology*, or more generally, philosophical language. Philosophical expressions are sometimes taken from ordinary language (as, for example, *arche*) but their ordinary meanings are later adapted to a new range of applications. The

so-called technical language of philosophy is the initial condition of precision in inquiry, and the evolution of philosophical doctrines consists to a great extent in the evolution of concepts. A doctrine or a philosophical system cannot arise, if it does not have available the proper concepts. The evolution of concepts leads to new questions. Without the right language, the questions remain invisible.

2. *Method*, or "a systematically applied means." Without method, there is accidental discovery, but there is no authentic research. Method counts no less than results because a good method contains in itself the promise of further results. Sometimes the new method can itself be a result. It is an important result because it usually opens up new areas of research. The result obtained by the Ionian philosophers of nature was the establishment of two research methods: (a) *analysis*—decomposition (usually only in thought) into simpler components, in order finally to reach the *elementary* components (the search for *arche*); (b) *induction*—transition from individual observations to general conclusions (plants and animals need water for life and therefore water is the *arche* of nature). It is not necessary to emphasize that this is only the first use of induction and is still obscured by hasty generalization.

And what did the first Greek thinkers give to the philosophy of nature in return?

First, the awareness that nature demands *intellectual explanation*. It cannot be taken as undiscussed data, but one must search for reasons explaining the structure of nature and even of (more generally) nature itself.

Second, the conviction that nature can be explained by reducing it to *elementary principles*. These principles do not have to be physical parts of a whole, like, for example, water or atoms; they can be metaphysical or logical elements, like for example *apeiron* or number.

Third, at the foundation of all those achievements lies hidden the tacit assumption that natural reality (and later all of reality in general) *can be explained*; that there are certain fundamental reasons thanks to which nature (reality) exists. Inquiry into such reasons is the *raison d'être* of philosophy (the so-called *problem of the rationality of nature*). That tacit assumption would become fully clear to philosophers only in the Middle Ages, when one of the most discussed topics would be the so-called *intelligibilitas entis*, or the *fundamental intelligibility of being*. The modern counterpart of that problem is the evermore discussed question of *why nature can be described mathematically*? Sometimes that question is called *the problem of the mathematicality of nature*.

European philosophy of nature began its history from the well-formulated problem of elementarity: what is the *arche* of the world? That problem created in researchers into nature an instinct for understanding through reduction to elementary principles. That very method of understanding continues to function in modern science. Is there ever any other way to understand something? Even *holistic* understanding relies on placement into wholes of once distinct parts. Besides, the category of wholeness can also be treated as an elementary principle. In that broad kind of understanding, the problem of elementarity becomes a case of the problem of the rationality of nature.

Biographical Notes

Thales of Miletus (c. 625–c. 547 BC), Greek philosopher and astronomer. He was born in Miletus. Not much is known about him. According to the historian Herodotus, Thales was supposed to have predicted an eclipse of the sun in 584 BC. In addition, it is believed that Thales was the first to attempt to explain physical phenomena naturalistically, departing from the traditional understanding of nature in terms of the activity of the gods.

Heraclitus of Ephesus (c. 540–c. 480 BC), Greek philosopher of nature. From his work *On Nature*, less than a hundred fragments remain. In explaining the nature of the world, Heraclitus asserted that the fundamental form of matter is fire; nature is subjected to constant changes, the result of which is a dynamic harmony of opposites, and the only constant principle is change itself.

Pythagoras (c. 580–c. 500 BC), Greek mathematician and philosopher. About 520 BC, he left his native Samos and settled in Croton. There he founded his own school and the associated Pythagorean movement, which had a religious character. The Pythagorean Society observed many rigoristic prescriptions (including dietary restrictions). The Pythagorean School was united by a common faith in a principle of the world which stated that "everything is number," and therefore nature is mathematically describable. The Pythagoreans made a significant contribution to the development of mathematics (among others, the Pythagorean Theorem and the discovery of irrational numbers).

Democritus of Abdera (c. 460–370 BC), Greek philosopher. He spent most of his life in his native Abdera (in what is now Turkey), though he spent some time in Athens. He was supposed to have written about 70 works on the philosophy of nature, logic, the theory of knowledge, mathematics, ethics, aesthetics, and medicine, but only a few fragments have survived. Democritus was the author of the atomic theory of matter. According to that theory, all bodies found in nature are made up of atoms—indivisible and unchangeable particles. Atoms do not differ from one another qualitatively; their differences are only quantitative—in the shape, the place, and the order of the atoms. The fundamental property of atoms is motion in the void which fills the space between the atoms.

Appendix: How Critical Thought Transformed the Ancient Picture of the World

The aspiration to understand the world, which had for many centuries been linked to mythological images, began gradually to undergo a transformation in ancient Greece at the turn of the sixth centuries BC. It was there that the first attempts at critical thought appeared. The conviction gradually arose that having a belief is not sufficient; beliefs require justification. Today, that seems obvious—critical thought lies at the foundations of all discourse about the world, but in the ancient world such a "mutation" in thought was a real revolution. The beginnings of philosophy were not easy. The religiosity of the Greeks was deeply rooted in their nature and any attempt at a rational explanation of phenomena met with sharp resistance. But the courage of those who were on the side of rationalism did not go to waste. Critical thought for long centuries demarcated the way of philosophy and of science.

It would not, however, be true to state, that Greek philosophy separated itself completely from religion. Some people think that, without religion, scientific thought would not be possible at all. The debt of science to religion is based on the fact that religion is the source of the conviction about the existence of a certain rationality in nature. One can say about religion that, on the one hand, it came into conflict with critical thought, and, on the other—through its belief in a rationality concealed behind the variety of phenomena—it became a condition of scientific thought.

The philosophy which arose at the turn of the sixth centuries BC had an almost completely cosmological character. The Ionian philosophers sketched a picture of the world which differed significantly from earlier mythical representations, although elements of beliefs and myths remained present in philosophy for a long time. In the mythology of the Greeks cosmogony was in principle identified with theogony—the world came into existence as a result of the gods, their wars and their passions. From the seventh century BC, the myth of the origin of the world written by Hesiod of Ascra is often called philosophical. For Hesiod presented in poetic form a theogony in which for each god there was a corresponding thing or phenomenon which were subject to him; the order of the origin of things corresponded to the order of the origin of the gods. One can recognize that poem as a "transitional form" in which gods already are only the symbols of things or phenomena. Mythic cosmogony was not, however, able to offer a genuine explanation of the origin of the world, and the question about the source of the genealogy of the gods remained unanswered. A time of a completely new way of thought—philosophical thought—was coming.

It is, at this point, worth saying a few words about the most important aspects of the transition from mythological thought to philosophy. They are:

- the demythologization of nature, or a departure from the presentation of particular aspects of nature as images, e.g., of gods;
- the appearance of a vision of an ordered Cosmos—in philosophical thought, the world was understood as a unity governed by principles intelligible to man;
- the search for general explanations for natural phenomena;
- the recognition of man as an observer who has no influence on the operation of the world;
- critical discussion of views;
- an aspiration to find coherent, consistent views.

In the new Greek thought appeared shortly thereafter:

- a distinction between the phenomenal world and reality; and
- the conviction that under the changeability of phenomena there was a hidden principle of permanence.

The development of critical thought also exerted an influence on the Greek understanding of God. For there appeared a God who was part of a philosophical system but did not directly fulfill any religious functions. He was the final intellectual closure of a system and later became known as "the God of philosophy" (in distinction from "the God of religion"). Such functions were fulfilled by Aristotle's First Mover and by Plato's Demiurge. So understood, God was often considered to be the foundation of rationality.

The transition from mythic to critical thought had one more, very curious aspect—the evolution of language. Greek mythology was almost entirely a matter of metaphor. It spoke about the lot of man and his powerlessness against the forces of the universe. The myths spoke in everyday language, which, in its religious role, took on metaphorical meanings. It made use of symbols to express that which was inexpressible. Critical thought with time developed a precise language of philosophical discourse. In the technical language of philosophy there was no longer any place for symbols, language was supposed to express its intended content unambiguously. The language of philosophy was clearly separated from the language of religion. The latter, because of the nature of its subject, had to remain metaphorical.

The effort of a small group of people, appreciating the power of human reason, opened the gate through which tens of generations passed and a gate which will probably never be closed.

Chapter 2
The Philosophical Myth of Creation—The Platonic Philosophy of Nature

1 Ideas and Their Shadows

The next important developmental step in the philosophy of nature was the result of Socrates' interest in virtue! The modern concept of virtue as moral correctness originates with Socrates. In order to formulate that concept, it was necessary to rise to a high level of abstraction. It is very characteristic that European philosophy began to sharpen its theoretical tools on problems connected with ethics. It was precisely on the terrain of ethics that the concept of *essence* first appeared. Socrates asked, for example: What is justice? Wanting to distinguish justice from related virtues, he sought those traits which were their essence and not just those which happen to be associated with justice. An awareness of the difference between the *constitutive traits*, which were its essence, and the *accidental traits*, which only happened to be associated with the given concept, was a major achievement of Greek philosophy. It produced Plato and has had an impact on all of European thought.

Plato, who was a disciple of Socrates, extended the concept of essences from the sphere of morality to all spheres of thought.[1] The genius of Plato told him to seek understanding of essences in the simplest cases. It is not surprising that it directed him to geometry (not without the influence of Pythagorean philosophy). Where, for example, should one search for the essence of a sphere? Not among material things, because in the material realm one can find only "simulacra of spheres," but not the "ideal spheres" about which geometry tells us. Despite that, the ideal spheres of geometry exist, for geometry shows us the laws of their existence. Here is the source of the *Platonic doctrine of a world of ideas (or forms)*. Things that are accessible to the senses are only the shadows of their ideas. The ideas exist really; the existence of things accessible to the senses are derivative in relation to the existence of ideas.

[1] This chapter is, in significant part, based on my article "*Timajos*—filozoficzny mit o pochodzeniu i naturze świata" *Analecta Cracoviensia* 17 (1985): 111–123.

In the *Timaeus*, Plato put the question:

> Do all those things which we call self-existent exist? Or are only those things which we see, or in some way perceive through the bodily organs, truly existent, and nothing whatever besides them? And is all that which we call an intelligible essence nothing at all, and only a name?[2]

For Plato explicitly formulated one of the most important dilemmas of philosophy: *essentialism*—essences exist and knowledge of them is possible, vs. *nominalism*—any kind of general knowledge, distinct from that which is perceived by the senses, is nothing more than words (names). The debate between those two views—in various forms—appears on nearly every page of the history of philosophy. In the Middle Ages, it took the form of the famous *debate about universals* (whether there exists something which corresponds to general concepts); in our times it has made itself known in the radical statements of the neo-positivists (nominalism) and the later reaction to them (not necessarily in the form of essentialism). Essentialism usually opens the road to metaphysics, nominalism is very often associated with extreme empiricism.

Platonic essentialism has two aspects:

1. *The Metaphysical Aspect*: the world of ideas exists (is), but it never becomes, while the world accessible to the senses becomes, but never is.[3] The following text from the *Timaeus* provides a commentary on that formulation:

> Wherefore also we must acknowledge that there is one kind of being which is always the same, uncreated and indestructible, never receiving anything into itself from without, nor itself going out to any other, but invisible and imperceptible by any sense, and of which the contemplation is granted to intelligence only. And there is another nature of the same name with it,[4] and like to it, perceived by sense, created, always in motion, becoming in place and again vanishing out of place, which is apprehended by opinion and sense.[5]

2. *The Epistemological Aspect*, which was already hinted at in the quotations above—knowledge about ideas is certain, knowledge about things accessible to the senses—only probable.

> The one is always accompanied by true reason, the other is without reason; the one cannot be overcome by persuasion, but the other can: and lastly, every man may be said to share in true opinion, but mind is the attribute of the gods and of very few men.[6]

The necessity of existence and the certainty of knowledge—these are the attributes of the world of ideas; contingency and probability—these are the traits

[2] Plato, *Timaeus* 51c, trans. Benjamin Jowett, in Edith Hamilton and Huntington Cairns, eds. *The Collected Dialogues of Plato* (Princeton: Princeton University Press, 1961).

[3] See ibid., 28a.

[4] This is about things which have the names of their ideas.

[5] Ibid., 51e–52a.

[6] Ibid., 51e.

of the world knowable to the senses. If geometry served Plato as a prototype for the doctrine of ideas, then we encounter there for the first time the philosophy of mathematics. Mathematics derives its certainty from the necessity of the world of ideas; it is divine knowledge because it gives a full knowledge of things which are not subject to change.

If things subject to sense perception are—as Plato asserted—the shadows of ideas, then it is clear why they can so effectively be described with the help of mathematics: they bear on themselves the mark of their origin. But that is a problem which can be found only embryonically in the thought of Plato. Only the rise and development of the empirical sciences will show this problem in its full sharpness. Many thinkers—consciously or not—will seek in Plato inspiration in dealing with this problem.

2 Becoming and Being

The claim that a world accessible to the senses "becomes but is not" raises the question: Why does the world become? The world requires that one provide a foundation or a reason for its becoming. The foundation of the world—according to Plato—is its creation. "What is it," Plato asks, "which always is and never becomes; and what is that which is always becoming and never is?"[7] The world of Ideas never becomes, but simply is, it is its own foundation. However, the becoming of a world cognizable by the senses is almost a synonym of being created. The world cannot become without a cause, and as soon as we begin to think in categories of "a cause leading to becoming" we approach a doctrine of the creation of the world. Plato emphasizes:

> Everything that becomes or is created must of necessity be created by some cause, for without a cause nothing can be created.[8]

In that way, one of the most important distinctions of the European philosophical tradition was born, namely the distinction between *necessary being* and *contingent being* (the terms themselves, of course, come from a later period); the first was identified with the Absolute or with God, the second—with everything which exists outside of Him.

Therefore it is no accident that the Platonic philosophy of nature was put in terms of a myth of the creation of the world. The fundamental philosophical truth about nature is its lack of necessity and its derivativeness in relation to the world of Ideas, in other words, that it is created. The *Timaeus*—Plato's myth about the creation of the world—was written near the end of the author's life. As one reads through the dialog, one sees how its style breaks down and the composition gets entangled in details. But Plato did not lose the subtlety of philosophical coherence. Through the mythic form of its narration, one can clearly see a powerful

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[7] See ibid., 28a.

[8] Ibid.

philosophical construction and it is perhaps the soundness of its philosophy which underlies the fact that so many of its mythological details, after twenty-some centuries, reveal a surprising similarity to certain discoveries of modern physics. But Plato is too experienced a thinker to attach importance to overly detailed inquiries. Certain knowledge is possible only with respect to ideas, although in investigating a world of becoming "we ought to accept the tale which is probable and enquire no further."[9]

In the Platonic myth, the creator of the world is the Demiurge, or (translating the Greek) the Artisan. But it is necessary to remember, that in ancient Greece an artisan was considered to be an artist. The world is a work of art of the Demiurge. The Demiurge fixes his eyes on the Ideas as models and shapes the world from an eternally existing material. The material existed until then "without reason and measure" only the Demiurge shaped it according to "form and number."[10]

3 The Prototype of the Concept of Space

The doctrine of the Ionian philosophers of nature concerning the *arche* of the world made a strong impression on the next generations of thinkers. For many, it became an unavoidable point of departure for their own inquiries, even if in the end they had to adopt principles that were contrary to or an improvement on those of the physiologists. In the *Timaeus* we read:

> Wherefore, the mother and receptacle of all created and visible and in any way sensible things, is not to be termed earth, or air, or fire, or water, or any of their compounds or any of the elements from which these are derived, but is an invisible and formless being which receives all things and in some mysterious way partakes of the intelligible.[11]

That Platonic "receptacle of all" calls to mind Anaximander's *apeiron* but contains aspects of Aristotelian pure passivity (prime matter), "which receives all things," or even of substance as the subject of various properties (accidents). Nevertheless, the term *chora*, for that is the term which the author of the *Timaeus* uses to designate that receptacle, he understands very idiosyncratically. The *chora* is a kind of medium between the sense world and the world of Ideas. Because things are extended in space, they exist in the *chora*, and that in turn is a condition for their cognizability. It is not surprising that some translators translate *chora* as "space." But it is not yet the later concept of space, understood as a completely passive container for bodies. *Chora* fulfills the function of a necessary condition both of becoming and of cognizability by the senses. E. T. Whittaker aptly wrote:

> Recalling that the Ideas are incorporeal, he argues that the earthly copy of an Idea cannot be able to arouse perceptions and thus qualify as a thing of sense, unless it is equipped, so to speak, with a location; this is a necessary condition if it is to be perceived at all. It is here

[9] Ibid., 29d.
[10] Ibid., 53b.
[11] Ibid., 51a.

> that *chōra* comes in, as a mediating agency between the two worlds, that of appearance and that of reality: it may be thought of as a substratum which remains when all the attributes of material bodies—weight, color, etc.—are abstracted from them. Moreover, the sensuous objects may be regarded as being actually constituted of *chōra*.[12]

Various meanings of the term *Chōra*			
Chōra as	*Chōra* as	*Chōra* as	*Chōra* as
Subject	Medium between the world of senses and the world of ideas	Space	The condition of becoming and of the cognizability of the world

4 Time: The Moving Image of Eternity

In his analyses of time, Plato rose to the heights of abstraction. We must credit him with the discovery of *the existence of the atemporal*. The experience of transitoriness is one of the most fundamental experiences of man. In prephilosophical thought, non-temporal existence seems to be unthinkable. Plato noticed how wrong we are when we apply that kind of intuition to the world of Ideas. Although we say of an Idea that "it was, is, and will be," in fact "'is' alone is properly attributed to [it]." And here appears a fundamental distinction:

> "Was" and "will be" are only to be spoken of becoming in time ... but that which is immovably the same cannot become older or younger.[13]

The Ideas are always the same, one cannot ascribe to them the concept of time and change. That atemporal kind of duration Plato calls *eternity*. Only a world subject to change becomes in time. In order to explain the nature of time, Plato resorted to the following allegory:

The Demiurge, in creating the world, wanted to make it similar to the model which he was copying, that is to some Idea. The Ideas exist in eternity, but the natures of eternity and of becoming are mutually exclusive. So it was necessary to make some compromise. Here is the dilemma and its solution:

> as this [first creature] was eternal, he sought to make the universe eternal, so far as might be. Now the nature of the ideal being was everlasting, but to bestow this attribute in its fullness upon a creature was impossible. Wherefore he resolved to have a moving image of eternity, and when he set in order the heaven, he made this image eternal but moving according to number, while eternity itself rests in unity; and this image we call time.[14]

So, according to Plato, *time is the moving image of eternity, lasting in unity, but moving according to number*. Time "moves according to number," but is designated according to a certain unity. How is that to be understood? Plato calls to mind

[12] E. T. Whittaker, *From Euclid to Eddington* (Cambridge: Cambridge University Press, 1949), 6.

[13] Plato, *Timaeus* 38a.

[14] Ibid., 37d.

Eastern images according to which time has the structure of a circle—the history of the world is a history of eternal returns. The author of the *Timaeus* advanced the conjecture that the heavenly bodies will someday once again have the very configuration which they had at some time in the past, the cycle of the universe will close, and everything will begin to occur again. The never-ending repetition of events is as close to eternity as the world can get.

The central problem of Platonic philosophy is the mutual relation between two worlds: the world of becoming, cognizable by the senses, and the world of existence and of Ideas (or, as we would say today, of physics and of mathematics); the problem of time is entangled in the very foundations of that relation.

5 Symmetries

The harmony and the beauty of the world are, for Plato, the harmony and the beauty of a living organism. In this respect, the author of the *Timaeus* was under the influence of the earlier Greek tradition, for which the world was rather an organism—and sometimes even a rational being—than a mechanical construction. The analogy between the universe and man (including in this analogy the human duality of soul and body) in the Platonic myth of creation has a significance that is not only a matter of juxtaposition.

In his description of "the body of the universe," one can see certain mechanistic features (for example, that body—according to Plato—is still composed of the four Greek elements: earth, air, fire, and water), but that mechanistic view is considerably softened by Plato's rationalism. The four elements cannot just be mixed with one another:

> there must be some bond of union between them. And the fairest bond is that which makes the most complete fusion of itself and the things which it combines; and proportion is best adapted to effect such a union.[15]

So, the Platonic world is a mathematical world. Theaetetus, a disciple of Plato, proved that there are exactly five regular polyhedra, that is, geometrical solids, of which all the vertices, edges, and faces are equal and of which the faces themselves are regular polygons; they are: the tetrahedron, hexahedron, octahedron, dodecahedron, and icosahedron.[16] The discovery of Theaetetus made a great impression on Plato. The most perfect (the most symmetrical) geometrical solid is the sphere, but second place, with respect to perfection, is taken by the regular polyhedra, later called *Platonic solids*. Because those solids are so perfect, it is necessary that they be used in the construction of the world. In Plato's opinion, the elements have a geometrical structure and their essential features can be reduced to the attributes of symmetry. And thus, for example, the element earth consists of small hexahedra,

[15] Ibid., 31c.

[16] See, e.g., David Hilbert and Stephen Cohn-Vossen, *Geometry and the Imagination*, trans. P. Nemenyi (New York: Chelsea, 1952), 89–93.

while the element fire consists of small “pyramids” (hexahedra). From the symmetry of the regular polyhedra, Plato tried to deduce all the physical properties of the elements, and then all the properties of the world. However much the Platonic realization of this project may seem to us today to be naïve, his philosophical postulates are striking in their boldness. In light of such considerations, contemporary physics' theory of elementary interactions, which considers the attributes of symmetry to be fundamental (although its symmetries are symmetries of dynamics and not static symmetries like those of the regular polyhedra), is one more attempt to implement Plato's program.

6 The Achievements of the Platonic Philosophy of Nature

So let us now mention a few of the achievements of Platonic philosophy that have had the greatest impact on later thought about nature.

1. The extension of Socratic thought about essence to all kinds of beings. From then, for many centuries, philosophy would try to ignore the contingent and to concentrate its attention on that which is necessary. Nevertheless, the recognition of certain beings as necessary and others as contingent would change from one philosophical system to another.
2. The condition of the existence of “things cognizable by the senses” (shadows) is the existence of the Ideas. The Ideas “harmonize” their shadows. The discovery of the existence of things different from those affirmed by the senses became the foundation for nearly all of metaphysics, though not all metaphysicians understood that existence in a Platonic way (i.e., as the existence of Ideas).
3. The theory of Ideas applied to “mathematical beings” created the first philosophy of mathematics (if one does not count the still relatively primitive speculations of the Pythagoreans), and the “theory of shadows” became the first attempt to explain why nature is mathematical.
4. The Ideas harmonize their shadows, but it is the shadows that exist now (“become”), because they have been created. With the doctrine of creation began to appear the distinction, later so fundamental to philosophy, between a necessary being and contingent beings.
5. In Plato's writings, the problems of time and space became the traditional problems with which every system of the philosophy of nature had to reckon. In discussing Plato's philosophy of time, it is worth taking note of the possibility of the existence of the atemporal (the persistence of the Ideas).
6. The Platonic theory of symmetry and its role in the reconstruction of the structure of the world—though long passively repeated and then forgotten—has undergone a surprising revival in theories of contemporary physics. Is this just a case of accidental convergence? Or does the relationship between Platonism and the contemporary mode of thought have deep roots? Perhaps further chapters will shed some light on these questions.

Biographical Notes

Socrates (469–399 BC), Greek thinker. He walked through the streets and squares of Athens with a conviction about his divine mission to teach people to care for their own souls. Together with the contemporary Sophists, he initiated philosophical inquiry into the problems of man and morality. He was accused by the Athenians of "the introduction of new gods and the corruption of the youth" and was condemned to death. He did not leave any writings behind him; Socrates' teachings, above all in the area of ethics, were transmitted by his disciples, chiefly by Plato. Socrates became the paradigm of a philosopher who lives according to the truth that he teaches and is prepared even to give his life for it.

Plato (c. 427–c. 347 BC), Greek philosopher. He probably came from a noble Athenian family which took an active part in the political life of Athens. After 399 BC, he left Athens and went to Sicily, where he encountered the Pythagoreans. On his return to Athens he founded (c. 387 BC) his Academy, the famous school which operated until its closure by the Emperor Justinian in 529 AD. He constructed an idealist philosophical system based on the primacy of immutable, eternal ideas over material beings. Plato's views had a great influence on European theology, politics, ethics, metaphysics, and logic; in particular, Plato had an influence on European philosophy of nature, founding a tradition according to which nature can be subjected to mathematical analysis. An expression of that is the inscription which was reportedly placed above the entrance to the Academy, forbidding entry to those who did not know the arcana of geometry.

Theaetetus (c. 414–c. 369 BC), Greek mathematician. He was a friend of Plato, who named one of his dialogs after Theaetetus. Probably Theaetetus contributed to the development of Euclid's theory of irrational numbers and also played a role in the development of stereometry.

Appendix: Platonism's "Ideas" in the History of Western Philosophy

Plato is one of the most influential thinkers in the history of philosophy. It is worth recalling Whitehead's remark that the Western philosophical tradition consists of a series of footnotes to Plato. As usually happens in such situations, the doctrine of a great thinker undergoes various transformations, sometimes taking it quite far from the original. All the more since—as is now well known—a significant part of Plato's doctrine was never written, but was passed down by oral tradition, which of course had an influence on its development and therefore on the changes that it underwent.

At the beginning of the Christian era, classical *Platonism* took the form of *Neo-Platonism* (Plotinus, Porphyry). That philosophy combined the thought of Platonism with elements of the doctrines of the Pythagoreans, of Aristotle, of the Stoics, and also of Eastern *gnosis*. The construction of Christian theology by early Church authors and Fathers (Origen, Pseudo-Dionysius, St. Augustine) was based primarily on Platonism and often on its Neo-Platonic version. That assured the dominance of thought connected to Plato towards the end of antiquity and in the first phase of the Middle Ages. In the thirteenth century, as a result of contacts with *Islamic* philosophy and thanks to the work of such scholars as St. Albert the Great and St. Thomas Aquinas there was a return to *Aristotelianism*.

As we saw, the Platonic philosophy of nature put a great emphasis on the use of *mathematics* in inquiry into the world. At the end of the Middle Ages and at the beginning of the modern period alongside the general growth of interests in ancient culture, the use of mathematics became the reason for ever more frequent appeals to Plato's thought. Galileo, Kepler, Newton, and the other creators of modern physics (most explicitly, Kepler) readily referred to Plato, although in their research they connected mathematical analyses with the conduct of controlled experiments, which brought them even nearer to the tradition of Archimedes than it did to that of Plato.

The later growth of empiricist and positivistic tendencies reduced the interest of scientists in their philosophical roots. But not for long. The successes of mathematicized physics could not help but raise questions about why applying mathematics in inquiry about the world is so effective. One of the positions on this question most widely held among mathematicians and theoretical physicists is the so-called *Platonic position*. Roughly, it holds that objects or mathematical structures exist objectively and independently both of the material world and of our cognition. Between that Platonic world and the physical world exists a *correspondence*, as a result of which, by inquiry into mathematical structures (to which experience points or which it *ex post* confirms), we can get information about the structure of the physical world. It is not necessary to add that many versions and varieties of that kind of Platonism exist. It is also certain that—besides the most general intuitions—they do not have very much in common with the original thought of Plato. In particular, Plato did not simply identify his world of Ideas with the world of objects or of mathematical structures, as Platonizing physicists and mathematicians generally do.

It should be mentioned that in addition to the *Platonizing* positions in the philosophy of science (and in particular in the philosophy of mathematics), there exist doctrines that are often called *anti-Platonic*. These are often associated with various forms of empiricism.

Among the strongest adherents of Platonism in the philosophy of science are the mathematician and logician Kurt Gödel and the mathematician and theoretical physicist Roger Penrose.

Gödel wrote: "It seems to me that the assumption of such [sc., mathematical] objects is quite as legitimate as the assumption of physical bodies."[17]

Penrose wrote: "My sympathies lie strongly with the Platonistic view that mathematical truth is absolute, external, and eternal, and not based on man-made criteria; and that mathematical objects have a timeless existence of their own, not dependent on human society nor on particular physical objects."[18]

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[17] "Russell's Mathematical Logic," ed. P. A. Shilpp, *The Philosophy of Bertrand Russell* (LaSalle: Open Court, 1989), 123–154, at 137.

[18] *The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics* (New York: Oxford University Press, 1989), 116.

Chapter 3
Aristotle's *Physics*

1 Introduction: From the World of Ideas to Individual Objects

Plato was both a great philosopher and a great poet. His philosophical system is at the same time an enchanting vision. Metaphor and symbol and sometimes calculated myth substitute for elaboration of details. In a period in which scientific details were not yet available, that was of undoubted use. One can always fill the symbolic margin with more up-to-date details. Aristotle, Plato's student, had the mind of a writer of prose. Thought does not have to be nicely phrased, but it should be as clear as possible. Not literary dialogs but lecture notes are the correct "literary genre" of philosophical inquiry. Aristotle gave the world its first comprehensively worked out philosophical system, of which the only end is satisfying the desire to know "what is true" and the only means to that end—faithfulness to the principles of logic and to the testimony of the senses. Those two means are usually called *criticism* (*rationalism*) and *empiricism*: both those names can be applied to Aristotle's system.

The transition from Platonism to Aristotelianism was a revolution not only from the point of view of philosophical method but also from the point of view of content. The Platonic essences of things exist in the world of Ideas. Aristotle places the essences of things in the things themselves. The essence of a thing is its substance. Aristotle's system is thoroughly substantialist. This is particularly true of its philosophy of nature. With Aristotle begins a centuries-long period of substantialism.

Aristotelianism survived through the Middle Ages and right up until the modern period. It is practiced even today, especially by philosophers of the neo-Scholastic movement.[1] The passing centuries put many interpretations on Aristotle and it is not easy today to dig down to the original thought of the Philosopher. But I do not

[1] See the numerous books and publications of Mieczysław A. Krąpiec. e.g., *Struktura bytu: charakterystyczne elementy systemu Arystotelesa i Tomasza Akwinu* (Lublin: Towarzystwo Naukowe Katolickiego Uniwersytetu Lubelskiego, 1963). Books attempting to offer a contemporary version of Aristotelian philosophy of nature include: Andrew G. M. van Melsen, *The Philosophy of Nature* (Pittsburgh: Duquesne University Press, 1954) and Stanisław Mazierski, *Elementy kosmologii filozoficznej i przyrodniczej* (Poznań: Księgarnia swiętego Wojciecha, 1972).

intend to write an elaborate study of his work. Rather, I would like to show the place of Aristotelianism in the course of the human efforts to understand nature. It is impossible to do that, of course, without giving some attention to the most important points of Aristotelian doctrine. In doing that, I will not, I think, go beyond the generally-accepted textbook interpretation.[2]

2 The Ontological Point of View

Aristotle initiated the tradition of methodological systematization. Before proceeding to the analysis of any problem, it is necessary first to determine the science to which the analysis of that problem belongs. But the classification of the sciences already to some extent presupposes a philosophy since the structure of the sciences—in the opinion of Aristotle—reflects the structure of reality. This is why Aristotelian debates about the divisions of the sciences and the delimitation of their competences contain within themselves much ontological speculation. A philosopher does not create new sciences and does not invent corresponding methods for them; he discovers them as a part of the reality that is already there.

Aristotle distinguished three kinds of "things" (beings): (a) things that exist separately and are immovable; (b) things that exist separately and are movable; and (c) things that do not exist separately and are immovable. Things existing separately—as we will soon see—are substances, the essence of which is based on the fact that they do not exist "in anything else." Subjection to motion must here be understood in the Aristotelian sense, as a broadly understood mutability. The three basic sciences correspond to those three kinds of things.

The division of the sciences according to Aristotle

Physics	Mathematics	First science
Things that exist separately and are movable	Things that do not exist separately and are immovable	Things that exist separately and are immovable

For physics deals with things which exist separately but are not immovable, and some parts of mathematics deal with things which are immovable but presumably do not exist separately, but as embodied in matter; while *the first science deals with things which both exist separately and are immovable*.[3]

[2]I must, however, note the debt I owe to Jean Ladrière, for I made great use of his manuscript, *Physique et Métaphysique.*

[3]Aristotle, *Metaphysics* VI.1, 1026a. Emphasis mine.

Aristotle sometimes calls first philosophy or theology “the first science;” today we use the terms “ontology” or “metaphysics.”[4] Its subject is “being as being and the attributes which belong to this in virtue of its own nature.”[5] The creation of the abstract term “being as being” and the science which corresponds to it—that is, metaphysics—is thought to be the most characteristic and the most significant achievement of Aristotle.

Ladrière thinks that the key to understanding the “metaphysical perspective” can be provided by the Aristotelian concept of *principle* or *beginning* (Greek *arche*). Aristotle begins his explanation of that term by giving a series of examples which he summarizes as follows: “It is common, then, to all beginnings to be *the first point* from which a thing either (a) is or (b) comes to be or (c) is known.”[6] The metaphor of a source or spring—but one from which comes something very important, such as being, becoming, or knowledge—illustrates the meaning of the term *arche.* Ladrière thinks that *arche*, so understood, reveals the chief goal of first philosophy. That is supposed to be a “return to the source,” a reconstruction of the motion of all of reality in the opposite direction (in the opposite direction—because in fact reality “flows” from the source, while we, in doing metaphysics, want to reach the source). Metaphysics then is a “source science.”[7]

The subject of metaphysics is being as being. The term “being” is predicated of many different things. Aristotle writes:

> . . . there are many senses in which a thing is said to be, but all refer to one starting-point; some things are said to be because they are substances, others because they are affections of substance, others because they are a process towards substance, or destructions or privations or qualities of substance, or productive or generative of substance, or of things which are relative to substance, or negations of one of these things or of substance itself.[8]

So we can see that keystone or the common denominator of Aristotelian metaphysics is the concept of substance. As Ladrière writes:

> For there is a fundamental understanding of the term “being,” there is a certain type of reality which is a being in the most proper sense, in the principal sense, i.e., a certain type of model for all the other possible meanings of the term being. That kind of being, that first modality according to which a being is realized, is substance.[9]

What then is substance? According to Aristotle[10] the concept of substance contains in itself the four following characteristics: (a) substance is the essence of a thing; (b) substance is the subject or substrate; (c) substance is something

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[4] The term “metaphysics” probably comes from Andronicus of Rhodes (first century BC), who, in his catalog of the works of Aristotle, placed works on first philosophy after the *Physics* (*ta meta ta physika*).

[5] Aristotle, *Metaphysics* IV.1, 1003a.

[6] Ibid., IV.1, 1013a. (Emphasis and distinction of points mine.)

[7] See Jean Ladrière, *Physique et Métaphysique*, 6–7.

[8] Aristotle, *Metaphysics* IV.2, 1003b.

[9] Jean Ladrière, *Physique et Métaphysique*, 8.

[10] Aristotle dedicates *Metaphysics* VII to the concept of substance.

individual; (d) substance is something separate (or existing independently). The term subject (*hypokeimenon*) literally means "that which lies under," but in the context of Aristotle's system that "under" means something very fundamental, without which everything that is not a substance cannot exist.[11]

Substances that can undergo motion are the topic of Aristotle's physics.

3 The Point of View of Physics

Six of the eight books of Aristotle's *Physics* are concerned with the analysis of motion. This is no accident. In *Physics* I.1 we read:

> We physicists, on the other hand, must take for granted that the things that exist by nature are, either all or some of them, in motion which is indeed made plain by induction.[12]

The fact that at least some objects are capable of undergoing motion is known by (is obvious on the basis of) induction, and therefore on the basis of experience understood in a certain way. But Aristotle raises the fact of the existence of motion to the level of principle. Being capable of motion is a characteristic trait of natural objects. One can say schematically that "nature is the realm of that which undergoes motion" (Ladrière). One must emphasize here that Aristotle is speaking not only about local motion, but about motion in the broad sense of any kind of change. Nevertheless—as Stanisław Mazierski so aptly notes—Aristotle's attention "was directed not as much to the existence of changeable things but to their changeability."[13]

Aristotle contrasts "natural being" with "artificial being" (for example, products of human art). Just as "art" is an external principle in relation to being, nature is an internal principle. Here, therefore, we encounter the concept of a principle which causes the ontological perspective to make itself known also in the physics of Aristotle.

Aristotelian physics is based on the assumption of *the intelligibility of motion* (*intelligibilitas motus*). Motion is intelligible because one can appeal to principles which render the concept of motion logically consistent and therefore make motion possible.

A serious difficulty in understanding the character of Aristotle's physics is that we usually associate the term "physics" closely with contemporary physics. If we want to reach the original meaning of the term "physics" in Aristotle, we should free ourselves of those associations. But it is not an easy thing to do, as is shown by the existence of many interpretations of Aristotle's physics. Here are some of them:

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[11] ". . . if there is no substance other than those which are formed by nature, natural science will be the first science; but if there is an immovable substance, the science of this must be prior and must be first philosophy" (Aristotle, *Metaphysics* VI.1, 1026a).

[12] Aristotle, *Physics* I.2, 185a, trans. R. P. Hardie and R. K. Gaye, in Richard McKeon, ed., *Aristotle*.

[13] Stanisław Mazierski, *Elementy kosmologii*, 133.

A. According to the traditional interpretation, Aristotle's physics is based exclusively on sense experience. If it accepts any "principles," it accepts only those which can be reached by a generalization of sense data, and from which can be deduced only conclusions which are in agreement with sense experience. "The source of certainty in Physics does not flow from reason, but from experience."[14]
B. The interpretation above changes when we understand sense experience differently. And, for example—in the opinion of Louis Bourgey—the experience on which Aristotle bases his physics is not

> methodically organized experience, but experience which is formed over the course of a life, the acquisition of which is not connected to any particular or privileged act, and which possesses a significance that is primarily practical and not at all scientific.[15]

Aristotle's *empeiria* would therefore mean "some kind of objectification of knowledge deriving from a certain kind of familiarity with a reality that can be known by the senses."
C. It is possible to go a step further and to say that what is "given" in Aristotle derives rather from his logic (or dialectic) than from any kind of experience. On that interpretation, Aristotle's physics would be "a methodological logic of the physical sciences."[16]
D. Recently, the view has become particularly popular that the chief task of Aristotle's physics is a determination of the conditions that make a knowledge of nature valid. Among the spokesmen for that view is Wolfgang Wieland. In his opinion, what Aristotle considers to be validating conditions were imposed on him by the language which he spoke. Nevertheless it is a fact that the structure of Aristotle's language to some extent reflects the structures which he ascribes to reality. On that interpretation, Aristotle's program of physics would call to mind Kant's question: how are the sciences of nature possible? It is worth mentioning that while Kant sought validating conditions for already existing natural sciences, Aristotle was to some extent only laying out a design for a science of nature.[17]

In light of all the discussions above, it is necessary to keep in mind that from the point of view of today, Aristotle's *Physics* is not a methodologically homogeneous work. Alongside the layer of Aristotelian philosophy of nature (which we

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[14]Pierre Duhem, *Le Système du Monde: Histoire des doctrines cosmologiques de Platon à Copernic* (Paris: A. Hermann, 1913), I: 139.

[15]Louis Bourgey, *Observation et Expérience chez Aristote* (Paris: J. Vrin, 1955), 54.

[16]"Une logique méthodologique de la science physique," Auguste Mansion, *Introduction à la Physique Aristotélicienne* (Louvain: Institut Supérieur de Philosophie, 1946), 215.

[17]Wolfgang Wieland, *Die aristotelische Physik: Untersuchungen über die Grundlegung der Naturwissenschaft und die sprachlichen Bedingungen der Prinzipienforschung bei Aristoteles* (Göttingen: Vandenhoeck & Ruprecht, 1962). On the topic of various understandings of Aristotle's physics, see the introduction to Lambros Couloubaritsis, *L'Evènement de la science physique: Essai sur la Physique d'Aristote* (Bruxelles: Ousia, 1980). Here one can find references to the authors cited in the text.

called Aristotle's physics above and about the meaning of which—as we saw—interpreters disagree), it contains elements of purely linguistic analyses, records of simple observations of ordinary experience, and the embryo of physics in the modern meaning of the word (in particular dynamics), including attempts—still rather clumsy—to formulate laws of motion in the form of equations.

It is impossible to deny the great significance of Aristotle's *Physics*. That work was not only an indispensable step on the way to the rise of the empirical sciences; it was most of all a great human exercise in establishing an awareness of the rationality (*intelligibilitas*) of nature. That rationality is the foundation and the lifeblood of the sciences of nature.

4 A Philosophy of Change

The very possibility of motion was, for Aristotle, a much more important problem that it would seem at first glance today. Indeed, "induction" testifies clearly to the fact that at lease some objects are in motion, but the arguments presented by Parmenides and Zeno of Elea raised the problem of motion to the level of metaphysical antinomy. Coming to be is a particular (though a very important) case of motion, and being—as Parmenides asserted—can come to be only from non-being; but because non-being does not exist, for anything to come to be is impossible. This kind of antinomy is transferred by Zeno of Elea to the case of motion in the sense of change of place (local motion). So, for example, a flying arrow shot from a bow is at each moment located in a particular place (and is therefore at rest) and at the same time leaving that place (and is therefore in motion).

So how is motion possible? How can one reconcile the testimony of the senses with the testimony of reason? Those questions express one of the central problems of Aristotle's physics. The solution of the dilemma is Aristotle's *theory of act and potency.* Let us suppose that in the course of a motion, A becomes B. In order for a motion to occur, B must be distinguished in some way from A. But on the other hand B must be connected in some way with A; otherwise, there would not be a motion but a disappearance of A and a coming to be of B (but that is impossible, as Parmenides showed). That which connects A with B is *potency*: A is in potency with respect to B. That which distinguishes B from A is *act*: B is in act with respect to A. When A becomes B potency is actualized.

The theory of act and potency leads to the Aristotelian definition of motion:

> We have now before us the distinctions in the various classes of being between what is fully real and what is potential.
> Def. *The fulfilment of what exists potentially, in so far as it exists potentially, is motion*.[18]

[18] Aristotle, *Physics* III.1, 201a (emphasis mine).

As examples of motion so understood, Aristotle mentions "learning, doctoring, rolling, leaping, ripening, ageing."[19] Many misunderstandings concerning the Aristotelian theory of motion result from the fact that his concept of motion is often limited only to local motion (change of place), whereas Aristotle himself writes:

> . . . there is no such thing as motion over and above the things. It is always with respect to substance or to quantity or to quality or to place that what changes changes.[20]

Therefore, Aristotelian motion is change very broadly understood and his theory of motion is simply a metaphysics of change.

In speaking of change it is not possible not to speak of time:

> . . . neither does time exist without change; for when the state of our own minds does not change at all, or we have not noticed its changing, we do not realize that time has elapsed . . . .[21]

Nevertheless, Aristotle does not link time only to mental phenomena (such as thought), but generally with movement. Here is his classical definition: "time is 'number of movement in respect of the before and after.'"[22] Therefore time is linked with the quantitative side of motion, to some extent it measures motion, but it measures by the differentiation of the parts of motion, which are "before" and which are "after."

Quantitative, qualitative and local motion are accidental motions, i.e., the change, which results from those motions does not reach the essence of things (their substance). The theory of substantial motion lead Aristotle to the doctrine called hylomorphism.

5 The Theory of Hylomorphism

In substantial motion, there is a change of substance. Aristotle's standard examples are the generation and death of living organisms. And here the analysis of change leading to the concepts of potency and act remains valid, but this time potency and act concern the essence and therefore it is possible to get to them only by rational analysis. When a sculptor creates a statue (accidental motion), the stone finds itself in potency to the reception of the act of a new shape. In substantial change—by analogy—it is also necessary to assume a kind of material fulfilling the function of potency and a certain shape creating the new substance. That material, inaccessible to the senses and purely potential, Aristotle calls *prime matter*, or for short matter (*hyle*), and the shape which constitutes the substance *substantial form*, or for short form (*morphe*). Neither prime matter nor substantial form are independent beings, but their combination creates a substance. Prime matter, being pure potentiality, is

[19] Ibid.

[20] Ibid., III.1, 200b.

[21] Ibid., IV.11, 218b.

[22] Ibid., IV.11, 219b (emphasis mine).

the same in all beings and as potentiality (to the reception of new forms) is the principle of change in the world.[23] Substantial form however causes a given being to be what it is, in other words, it determines its membership in a particular "kind" of being. Substantial form can be considered to be a Platonic Idea which has descended from the abstract world of essences to beings cognizable by the senses and which, together with prime matter, creates their substance.

The doctrine of the composition of substance from matter and form, which later commentators have called the *theory of hylomorphism*, has a central place in the Aristotelian philosophical system and occupies also had a great impact on the later fate of European philosophy of nature.

6 The Principles of Aristotle's Dynamics

Aristotelian metaphysics of motion could not leave to one side purely dynamic problems. What is more, considering the absence yet of methodological demarcations between philosophy and the empirical sciences, the dynamic solutions of Aristotle were not able to separate themselves from his metaphysics. The distinction, so fundamental to Aristotle's mechanics, between *natural motion* and *violent (forced) motion* was required by his metaphysics. Since the appeal to the essence, or to the nature, of a thing is the ultimate explanation, the identification of a motion as natural brings inquiry to a close. Indeed, taking into account the Aristotelian definition of nature: "nature is a source or cause of being moved... in that to which it belongs primarily,"[24] an explanation appealing to the naturalness of motion has the character of an identification. Indicating the cause is necessary only for those motions which are not natural, but are violent (forced).

In Aristotle's opinion, local motion is the primary kind of motion[25] and the dynamics created by Aristotle concerns only local motion. Light bodies move upwards by natural motion; heavy bodies, downward. All other kinds of motion have to be forced by some kind of cause, which Aristotle also calls a moving factor.

Considering forced motions, Aristotle originated the science of mechanics; he was also close to formulating an equation of motion. That equation is easy to reconstruct from Aristotle's statements[26]; it looks as follows:

$$\mathrm{A} = \mathrm{B}\frac{\Gamma}{\Delta}$$

[23]In Ancient Greek, the word *hyle* originally meant "wood." It is worth keeping in mind the "organic" origin of the term *hyle* in order to avoid the modern ordinary meaning of the word "material."

[24]Ibid., II.1, 192b (emphasis mine).

[25]See ibid., VIII.7, 260a–261b.

[26]Aristotle writes, for example: "in the same time D the same force A will move (1/2) B twice the distance G, and in (1/2) D it will move (1/2) B the whole distance for G" (*Physics* VII.5, 250a). Parentheses added for clarity.

where, in accordance with Aristotle's terminology A is a movng factor or force, B—the thing moved, Γ—the distance traveled, and Δ—the time in which the motion occurred. The error in this equation is twofold.

First, Aristotle put the speed Γ/Δ (in essence, the mean speed) where later Newton would correctly write acceleration. That error, paradoxically enough, resulted from an excessive faithfulness to ordinary experience. If Aristotle had been able to ignore effects connected with friction and air resistance, perhaps a correct mechanics would have been attained even in antiquity. Nevertheless, he was not able to do that; the problem lay in his own statement about the impossibility of a vacuum; his fundamental principles did not allow him to overlook the fact that motion must always occur in some kind of medium.[27]

Second, an equally important source of error for Aristotle was his use of the unclear and only intuitively understood concepts of "moving factor" and "moved object." Science had to wait for many centuries until the evolution of those concepts led to the Newtonian definitions of force and mass. Only then was mechanics able to show perfect agreement of its predictions with experimental results. The evolution of concepts is a component of the progress of science as important as is the empirical collection of information about the world. What is more, those two elements are completely dependent on one another. Without their mutual resonance, there would be no real progress.

The error in Aristotle's dynamics did not remain without certain philosophical consequences. From the Aristotelian equation it follows that if "force" (the moving factor) is equal to zero, then the speed Γ/Δ is also equal to zero, i.e., the body is at rest. In other words: force is indispensable to the maintenance of motion. From here comes the principle: "Everything that is in motion must be moved by something else," which led Aristotle to the acceptance of a First Mover.[28]

In the Newtonian version of the (second) law of dynamics—as is known—force is necessary not for maintaining motion but for inducing acceleration. That fact eliminates the mechanical premise of the argument for the existence of a First Mover. It is necessary, however, to remember that for Aristotle motion is not only local motion and later Christian commentators on Aristotle did not limit themselves, in their arguments for the existence of a First Mover, to local motion.[29]

Aristotle's mechanics, supplemented as needed with elements of his metaphysics and with prescientific intuitions as well as with certain convictions inherited from

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[27] Stephen E. Toulmin and June Goodfield, *The Fabric of the Heavens: The Development of Astronomy and Dynamics* (New York: Harper, 1961), 97–100, interpret the Aristotelian equation mentioned above as describing motion in a resistant medium; in such an interpretation, that equation would not be a counterpart of the second principle of Newton's dynamics, but of Stokes' Law in contemporary physics.

[28] Here is the classic argument of Aristotle: "If then everything that is in motion must be moved by something, and the movent must either itself be moved by something else or not, and in the former case there must be some first movent that is not itself moved by anything else, while in the case of the immediate movent being of this kind there is no need of an intermediate movent that is also moved (for it is impossible that there should be an infinite series of movents, each of which is itself moved by something else, since in an infinite series there is no first term)" (*Physics* VIII.5, 256a).

[29] See, for example, the famous "first way" of St. Thomas Aquinas, *Summa Theologiae*, I, q. 2, a. 3.

tradition, led him to the construction of a cosmological system which placed the earth at the center of the universe, surrounded by concentric spheres deriving their motion from the First Mover. Aristotle described his cosmological system in his work *On the Heavens*.[30] That work was one of the first evolutionary links in a chain which was to lead to modern astronomy and cosmology.

7 The Significance of Aristotle's Physics

Aristotle's system of physics was a great and—it must be said—imposing effort of the human mind in the understanding of nature. It was without doubt a "premature synthesis,"[31] but a synthesis of great importance. The feeling of understanding which that system seems to give is all the more surprising since the empirical data lying at its foundations are poor, imprecise, and often simply mistaken. It seems that the feeling of understanding of which we are speaking assured Aristotle's system of a great vitality: Even today there are people who believe that Aristotle's explanations go further than do those which can be had from contemporary physics. Perhaps that testifies to a certain internal dynamism of man, who feels satisfied when he is able to take seemingly incomprehensible elements and combine them into a coherent theoretical structure.

Aristotelian explanation stops at the moment when one reaches the nature of a thing. The nature of a thing is that which Aristotle called *the essence of the thing if it appears in action.* The essence of a thing is of course a substance, with its main function as a subject of traits or accidents—and in that sense one can speak of substantial explanation in Aristotle.

An important question arises: How can one get to the essence of a thing, i.e., to its substance? Later philosophers, relying on Aristotle, postulated the existence of a special power in man, called "intellectual intuition," which would make possible the "reaching of principles."[32] (Is this yet one more manifestation of the dynamism of man, which we mentioned above?) It is a fact, however, that for Aristotle himself, the analysis which finally leads to the discovery of the essence of a thing often happens by means of analysis of the meanings of statements about the given thing. In that sense, it is possible to say that Aristotle's ontology is the ontology assumed in ordinary language.[33]

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[30] See the next chapter.

[31] "The Premature Synthesis" is the title of the chapter in which S. E. Toulmin and June Goodfield (op. cit., 90–114) discuss the physics and cosmology of Aristotle.

[32] Stanisław Kamiński and Mieczysław A. Krąpiec, *Z teorii i metodologii metafizyki* (Lublin: Towarzystwo Naukowe Katolickiego Uniwersytetu Lubelskiego, 1962), 329–330.

[33] And so, for example, semantic analyses of the phrase "one thing is in another" (*Physics* IV.3, 210a ff.) lead to the determination of the nature of place; analyses of the terms "before," "after," and "now" (*Physics* IV.11, 218b–220a) lead to the determination of the nature of time. See also *Physics* V.3, 226b–227a. In those passages, linguistic analyses are introduced in a transparent way;

Aristotle's ontology of substance became the most important rival to Plato's philosophy. Over the course of the centuries to come, those two systems shared a dominant position in thought about nature. The last years of antiquity and the first part of the Middle Ages were subject the influences of Plato (chiefly in its neo-Platonic version), the second part of the Middle Ages were almost completely Aristotelian. During the Renaissance, Plato once again began to exert an influence, but the rise of the empirical sciences for some time slowed the interest in philosophy. At the end of the nineteenth century and in the first half of the twentieth, Aristotelianism once again became important, mainly as a result of the development of neo-Thomism, and at the present time "philosophizing physicists" readily make reference to Plato. All of that testifies to the great importance of those two philosophers, an importance which can be fully appreciated only after tracing all the most important events in European philosophy of nature; from antiquity right down to the present day.

Biographical Notes

Aristotle (384–322 BC), the son of Nicomachus, court physician of Phillip II, King of Macedonia, and Phaestis, was born in Stagira. The sources report that he was Plato's most outstanding pupil. Nevertheless—according to Diogenes Laërtius—he left Plato even during the master's lifetime. In the years 342–335 he was tutor to the young Alexander the Great. After Alexander's accession to the throne of Macedonia, Aristotle returned to Athens where he founded his own school, the Lyceum. Aristotle's school was called "peripatetic," a name which took its origin from the fact that Aristotle was supposed to have walked about (*peripatein*—to stroll, to take a walk) while philosophizing with his students. In 323 BC, Aristotle was accused—as Socrates had once been—of impiety; in order to avoid sharing Socrates' fate, Aristotle left Athens and sought refuge in Chalcidice, A year later, he died.

At his death the philosopher left many writings. Laërtius writes that he wanted to express in them the following views:

> There is in philosophy a twofold division; one practical, and the other theoretical. Again, the practical is divided into ethical and political, under which last head are comprised considerations affecting not only the state, but also the management, of a single house. The theoretical part, too, is subdivided into physics and logic; the latter forming not a single division, turning on one special point, but being rather an instrument for every art brought to a high degree of accuracy.... As a natural philosopher, he was the most ingenious man that ever lived in tracing effects back to their causes, so that he could explain the principles of the most trifling

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very often however a "linguistic intuition" suggests to Aristotle solutions to ontological problems in a way that is not so transparent.

> circumstances: on which account he wrote a great many books of commentaries on physical questions. . . . He has also given other definitions on a great many subjects, which it would be tedious to enumerate here.[34]

Appendix: Aristotelianism and Platonism—The Rivalry of Systems

It is difficult to overestimate the significance of Aristotle for the future development of philosophy and of the sciences. In philosophy, Aristotle initiated one of the two main lines of development—alongside the line initiated by Plato—which would be interwoven in the history of thought and which would by turns determine the dominant tendencies. Although from the point of view of today, the majority of Aristotle's scientific conceptions turn out to be false, it would be difficult to find any contemporary science (at any rate belonging to the family of classical sciences) which cannot be found in embryonic form in the writings of Aristotle. Nevertheless, in the context of his time the achievements of the Stagirite are indeed impressive. He constructed the first *scientific system* based on a uniform method. The scientific parts of that system (especially that part belonging to biology) were without doubt confirmed by rich empirical body of data (although it was too often and too quickly interpreted in light of the principles of the whole system). Aristotle made every effort to ensure that the entirety of his system was controlled by *logic* (chiefly syllogistic logic), which he created with this system in mind.

In the final phase of antiquity, in the period of the Barbarian invasions and the migrations of peoples, knowledge of Aristotle was lost in the West. That was the result both of the loss of his scientific writings and of the fact that Greek was forgotten. As we saw in the previous chapter (see Appendix) the end of antiquity and the beginning of the Middle Ages was a time when Platonic philosophy was dominant and it was precisely to this philosophy that the emerging and then rapidly developing *Christian philosophy* tied its fate.

However, thought based on Plato—in every case on the version which the Middle Ages inherited—had a weak point: the philosophy of nature. The myth of the creation of the world, narrated in the *Timaeus* and usually understood too literally, could not in the long run replace a solid scientific knowledge. Therefore, when in the thirteenth century, by way of the Arabs, the West began gradually to gain a familiarity with the scientific writings of Aristotle (first thanks to translations into Latin from Arabic and later directly from Greek), their acceptance was only a matter of time. The resistance of the already well-established theological tradition was strong, and not only because of an otherwise understandable inertia in human thought. Some points of Aristotle's doctrine—especially his affirmation of the eternity of the world—appeared to be irreconcilable with Christian orthodoxy. However,

[34] Diogenes Laërtius, *The Lives and Opinions of Eminent Philosophers*, trans. C. D. Yonge (London: Bohn, 1853), V.13.

neither prohibitions nor official condemnations helped. (The most famous of these was the condemnation by Stephen Tempier, bishop of Paris, in 1277 of 219 theses ascribed, not always correctly, to Aristotle). The newly established universities needed a reliable scientific knowledge, and a philosophy of nature based on it, too much to submit to prohibitions. Besides, Church authorities made more and more exceptions and allowed study of the writings of Aristotle "for scientific purposes." The rest was done by thinkers of the caliber of St. Albert the Great and St. Thomas Aquinas. They showed that it is possible so to interpret the doctrine of Aristotle that not only is it not inconsistent with Christian doctrine, but it can be a better foundation for it than was the philosophy of Plato.

On the question of the *eternity of the world*, a great role was played by claim of St. Thomas Aquinas that, in fact, philosophically—on the basis of purely rational considerations—it is not possible to prove that the world had a beginning in time (and therefore in that regard Aristotle was right), but it is possible to prove rationally that the world is created by God (the argument here is from the contingency of the world). Therefore, theoretically it is possible to have a world that exists *eternally*, but is *created* by God. The thesis about the beginning of the world in time is a theological thesis (because it is based on Revelation) and not a philosophical thesis.

Over the course of a few generations, Christian theology changed from a Platonic theology to an Aristotelian one. During the next several councils, St. Thomas' *Summa Theologiae* was placed next to the Bible on the conciliar altar. It was not, therefore, surprising that, when history came full circle and European thought, under the influence of newly emerging sciences, returned to Plato, a sharp clash arose. This time the Church lacked thinkers of the caliber of Albert the Great and Thomas Aquinas. The atmosphere of the Counter-Reformation did the rest. The "Galileo Case" was unavoidable. As a matter of fact, it was not so much an issue of whether it was the earth or the sun that moved; it was rather an issue of whether the old, Aristotelian picture of the world, to which theology had grown so close, would have to be replaced by the new picture that had emerged from the mathematico-empirical sciences, or not. It is possible to suppose that even without Galileo the battle between the old physics and the new nevertheless, in one way or another, would have played itself out.

Chapter 4
Aristotle's Method of Cosmological Speculation

It may seem evidence of excessive folly or excessive zeal to try to provide an explanation of some things, or of everything, admitting no exception. The criticism, however, is not always just: one should first consider what reason there is for speaking, and also what kind of certainty is looked for, whether human merely or of a more cogent kind. When any one shall succeed in finding proofs of greater precision, gratitude will be due to him for the discovery, but at present we must be content with a probable solution.

Aristotle, *On the Heavens*, II.5

In this chapter, we will discuss a small work of Aristotle entitled *On the Heavens*[1]; it contains a presentation of his astronomical and cosmological views. Many things have already been written about Aristotle's astronomy and cosmology[2] and to repeat them would go beyond the intended scope of this work, but a quick look at the method of Aristotle's cosmological speculations will be a useful supplement to our knowledge of his system of the philosophy of nature.

It is especially when there is a shortage of adequate observational data that views about the structure of the universe depend strongly on philosophical convictions. And if one adds to that the fact that for nearly twenty centuries Aristotle's cosmology formed the standing picture of the universe, then attention paid to this little work will prove to be all the more justified. One must read *On the Heavens* with respect. Although nearly all the conclusions found in it turn out to be mistaken, it is still one of the two works of antiquity—the other being Plato's *Timaeus*—which initiated a long train of research leading to today's successes in the field of cosmological research.

Aristotle's *On the Heavens* is an astonishing example of how a system can be both logical and false. Aristotle, explicitly or implicitly, accepted several

[1] Translated by J. L. Stocks, in McKeon, ed., *Aristotle*.

[2] See, for example, Stephen E. Toulmin and June Goodfield, *The Fabric of the Heavens: The Development of Astronomy and Dynamics* (New York: Harper, 1961), 105–114; A. Pacholczyk, *The Catastrophic Universe* (Tucson: Pachart, 1984), Chap. 1; S. J. Dick, *The Plurality of Worlds* (Cambridge: Cambridge University Press, 1982), Chap. 1.

assumptions concerning the fundamental concepts of the philosophy of nature; all the rest followed nearly automatically by logical deduction. Only here and there did the deduction break down, giving place to arguments that only seemed logical. One gets the impression that the complicated nature of the cosmological problem overwhelmed the modest logical means available to Aristotle.

It is puzzling how seldom Aristotle appeals to observation and experience—very rarely to astronomical observations and always only to ordinary experience. One of the few places in which the Philosopher calls for help on the testimony of the senses (and that in a negative sense, i.e., making an appeal about something on which the senses are silent) is his disagreement with the view of the Pythagoreans, who maintained that the friction between adjacent heavenly spheres makes harmonious sounds (the "harmony of the spheres").

> Melodious and poetical as the theory is—Aristotle replies to the Pythagoreans—it cannot be a true account of the facts. . . . But if the moving bodies are so great, and the sound which penetrates to us is proportionate to their size, that sound must needs reach us in an intensity many times that of thunder, and the force of its action must be immense. Indeed the reason why we do not hear, and show in our bodies none of the effects of violent force, is easily given: it is that there is no noise.[3]

In several other places, Aristotle appeals to experience, but by experience he understands . . . universal conviction; for example:

> Our theory seems to confirm experience and to be confirmed by it. For all men have some conception of the nature of the gods, and all who believe in the existence of gods at all, whether barbarian or Greek, agree in allotting the highest place to the deity. . . .[4]

In that way, despite appearances, Aristotle investigates not the universe, but only his own assumptions.

What are those assumptions? Above all: 1. the existence of four fundamental elements—components—of natural bodies: fire, air, water, and earth; 2. everything that is composed of these elements, strives to occupy its "natural place," which for heavy bodies is the center of the earth, which is at the same time the center of the world, and for light bodies, the "periphery of the world;" 3. most perfect is circular motion; it is the natural motion of the fifth element, which is called the cosmic aether; 4. the heavenly spheres are built from the cosmic aether. The aether is more perfect than the other elements and, in contrast to them, is immutable and indestructible.

Many of Aristotle's arguments are based on "the axiom of perfection": that which is less perfect must yield its place to that which is more perfect. "Nature is ordered in the best way possible."[5] Just as for Plato, the concept of perfection is connected to symmetries (that is more perfect which is more symmetrical),[6] so for Aristotle, it

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[3] Aristotle, *On the Heavens* II.9, 290b–291a.

[4] Ibid., I.3, 270b.

[5] Ibid., II.5, 288a.

[6] See above, Chap. II.5.

is shaped by standards universally accepted in Greek culture (symmetries are only one of those standards).

The characteristically Greek "fear of the infinite" is a tacit axiom, which exerts a powerful influence on Aristotle's cosmological conclusions. Although Aristotle takes three chapters to prove that "the world is not infinite," it seems that all the arguments he cites are rather rationalizations in defense of a certainty assumed in advance. If the universe embraces everything that exists and at the same time it is not spatially infinite, then Aristotle has no option other than to imagine the world in the shape of a sphere (for that is the most perfect geometrical solid), outside of which there is nothing "neither place, nor void, nor time."[7]

But—curiously enough—the fear of the infinite does not extend to the temporally infinite. Apparently, for the Greeks the concept of a beginning in time was harder to grasp by intuition than was the concept of infinite time. The difficulty of that latter notion the Greeks obviated by linking it to the circular motion of the spheres. Infinite time is not so much a straight line as it is a closed circle, repeating the course of history again and again.[8]

Everything ceases to move when it comes to its proper place, but the body whose path is the circle has one and the same place for starting-point and goal.[9]

Aristotle was, however, aware of the fact that much in his cosmological system depends on its causal assumptions. In the course of his lectures, we more than once encounter the warning: "[it] will be clear from what has been said to any one who believes in our assumptions . . ."[10] or "the result is that we must either abandon our present assumption or assert that . . ."[11]

However, the entire tone of the work suggests that Aristotle understood warnings of that type as one understands rhetorical questions to which the questioner thinks the answer is obvious. It did not, however, occur to Aristotle that the obviousness could be a result of habits of thought, and not necessarily a reflection of the actual state of affairs.

Where Aristotle depended on authentic observation, he immediately got good results. So, for example, his observations of lunar eclipses led him to a correct conclusion about the sphericity of the earth:

> Since it is the interposition of the earth that makes the eclipse, the form of this line will be caused by the form of the earth's surface, which is therefore spherical.[12]

The author of *On the Heavens* is at the same time the author of the *Physics* and of the *Metaphysics* and without a doubt he thinks "within the framework" of his philosophical system. *On the Heavens* consists of four books, of which the last two are

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[7] Aristotle, *On the Heavens*, I.9, 279a.

[8] See above, Chap. II.4.

[9] Aristotle, *On the Heavens*, I.9, 279b.

[10] Ibid., I.3, 270b.

[11] Ibid., I.8, 277a.

[12] Ibid., II.14, 297b.

basically the philosophical justification of his cosmological principles. Today, from the perspective of twenty-three centuries, it is clear how much more successful than abstract speculation critical observation could be. Once again, a truth discovered only in the twentieth century is confirmed: There are no observations independent of theory (and therefore, in a certain sense, of speculation). It is precisely theory which must prompt the researcher, what it is worth observing and how one should observe it.

I will mention here two methods of justification here which Aristotle uses in his astronomical work. The first are the analyses of the meanings of terms taken from ordinary language. Contemporary analytic philosophers can see Aristotle as their precursor. But in Aristotle, linguistic analyses are transformed imperceptibly into analyses of reality, words begin to represent things, and purely linguistic results become theses of his system.[13]

The second method is based on distinguishing all the possibilities and eliminating each in turn, until their remains only one. That one remaining possibility is of course the position which Aristotle accepts. In that way, polemics with other systems replaces the necessity of justifying one's own view. What is more, sometimes Aristotle is able to distinguish only what appear to be all the possibilities and those which are distinguished are not always different from one another. The history of science would often show that nature is able to surprise us with unexpected possibilities, but in order to see these surprises, it is usually necessary to step outside the hitherto available set of concepts.

The question arises: to what extent is the development of science driven by an internal logic proper to science itself, and to what extent is it the result of accidental circumstances? How would the history of science have gone had one man—Aristotle—had a greater inclination to looking and manipulating and less to arguments for and against? If in his times and in his cultural circle Aristotle had been a different philosopher and a different scientist than he was?

We have a right, and even an obligation, to look at Aristotle with the eyes of today, but we must not lose the historical perspective. Today we are richer with respect to the mathematico-empirical method of investigation, but we must remember that the first steps towards this method were based on the decision to face nature only with the help of human reason. Those steps were taken by the human race in ancient Greece, and Aristotle was among those Greeks to whom we owe the most. The words of Aristotle used as a motto for this chapter show explicitly that he understood well the risks of those first steps.

Of the followers of Thales of Miletus, Aristotle wrote:

> These thinkers seem to push their inquiries some way into the problem, but not so far as they might.[14]

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[13] See, for example, all of Chap. XI.

[14] Ibid., II.13, 294b.

In that remark, Aristotle showed his genius. Research must be taken as far as the problem allows. And therefore to the complete liquidation—solution—of the problem. And that is why the history of cosmology continues.

Appendix: Ancient Ideas About the Structure of the Universe

The beginnings of Greek astronomy must be sought already in the sixth century BC. The first philosophers (Thales of Miletus and Anaximander) tried to describe the nature of the heavenly bodies. Initially, astronomical considerations were accompanied by the conviction that the earth is flat, but already Parmenides of Elea (seventh to sixth centuries BC) mentioned its sphericity.

Almost all the astronomical systems of ancient Greece were *geocentric* systems. According to Plato, the world is a sphere, in the middle of which is located the immovable earth. The stars rotate around it on spheres of their own. The motions of the heavenly bodies are uniform and circular. Eudoxus of Cnidus, a disciple of Plato, constructed a mathematical geocentric model on the basis of the science of his teacher.

1. *Eudoxus of Cnidus* (c. 408–c. 355 BC) created the so-called system of *concentric spheres*, which explained the motions of the planets well. The spheres moved around the earth, as the center of the universe, with uniform circular motion. The axes of those spheres are inclined to one another at such angles that the motions of the spheres depend on one another—the motion of the outside sphere is transferred to the inside sphere. The motions of the sun and of the moon are described by three spheres for each of those bodies. Each of the five then known planets (Mercury, Venus, Mars, Jupiter, and Saturn) have four spheres while all the stars are moved by a single, outermost sphere. Callippus of Cyzicus (fourth century BC), a pupil of Eudoxus, asserted that 27 spheres were too few for an accurate description of the motions of the heavenly bodies and created a system based on 34 spheres. Aristotle increased the number of spheres to 55 and incorporated that model into his system.
2. *Aristarchus of Samos* (c. 310–230 BC) was the creator of an *heliocentric* theory exceptional for that time. The Alexandrian astronomer and mathematician was the first researcher who made observations of the sky. Aristarchus proposed a theory according to which an *immoveable sun* is located at the center of the universe and the earth undergoes two kinds of motion—a *rotational* (daily) motion around its own axis and an *orbital* (annual) motion around the sun (the first to propose the hypothesis that the earth rotates was probably Heraclides of Pontus, a Greek astronomer contemporary with Aristotle). Aristarchus' heliocentric theory passed almost without notice. Despite the brilliant intuition of the astronomer, he was not able to overcome the authority of Aristotle and in later centuries, when the theory of Ptolemy appeared, the heliocentric system of Aristarchus was completely forgotten. It is worth mentioning that Aristarchus of Samos was the first astronomer to attempt to calculate the distance of the sun and of the moon from

the earth on the basis of observation of the heavens. Although his results were far from the truth, what is important is the very fact of the application of an *empirical method* in this area of science, which had earlier been based entirely on conjecture.

3. *Claudius Ptolemy* (c. 100–c. 178) in his work *Mathematike syntaxis* ("The Mathematical Treatise"), known in the Middle Ages also under the name of the *Almagest*, offered another mathematical model to explain the heavenly motions of the planets. According to Ptolemy, the earth occupies the central place among all the heavenly bodies. Around it, circle the seven "planets," or the "wandering stars": the moon, Mercury, Venus, the sun, Mars, Jupiter, and Saturn. Ptolemy replaced Aristotle's spheres, which were supposed to be physical bodies, with abstract *geometrical orbits*. In order to explain the peculiarities observed in the motions of the planets, especially their retrograde motion, Ptolemy held that it is not the planets themselves that move on the orbits, which are called *deferents*, but the centers of circles called *epicycles*, while each planet moves on its own epicycle. Earth is not located exactly in the center of the deferents, which was supposed to bring the model into closer alignment with observations. Outside the orbits of the planets was supposed to be the immoveable sphere of the *fixed stars*. Ptolemy's system was universally accepted for the next fourteen centuries although the differences between the observations and Ptolemy's system continued to increase. In the Middle Ages, in order to save the system, more and more epicycles and deferents were added to it. Only in the fourteenth century, at the end of the Middle Ages, Nicholas Oresme (1320–1382), bishop of Lisieux, considered the possibility of the motion of the earth relative to immoveable heavens. Nicholas of Cusa also mentioned the motion of the earth in the fifteenth century, although only Nicholas Copernicus in his work *De revolutionibus orbium coelestium* (*On the Revolutions of the Celestial Spheres*), published in 1543, broke the paradigm of ancient thought and presented a *heliocentric* theory, which became a turning point in views about the structure of the universe.

Chapter 5
Descartes' Mechanism

1 The Road to the Empirical Method

To the extent that Aristotle's metaphysics was baptized by *St. Thomas Aquinas* (c. 1225–1274)—chiefly by introducing and emphasizing the distinction between contingent being and Necessary Being—Aristotle's study of nature could be transferred almost immediately to the foundation of Christian thought. The only correction required by theology was a reconciliation of the dogma of the creation of the world with the philosophical reflection on nature and even that was rather a matter of metaphysics than of the philosophy of nature. Experience was able to force more important changes in the structure of the philosophy of nature, but that experience grew only slowly. In the eleventh century, in this regard, the school of Chartres (which remained under Platonic influence) stood out. Later, *Islamic science*, in its encounter with European thought, had—perhaps—a chance to initiate a new epoch in the study of nature, but it did not take advantage of this possibility. After the fall of the school of Chartres, its traditions in the philosophy of nature were taken over by the English *Oxford school* (twelfth century) along with *Roger Bacon*, who not only conducted various experiments himself but was also a theoretician of the experimental method. The turn away from the earlier Platonic inspiration in investigation of nature and towards Aristotelianism was made in the works of *St. Albert the Great* (1193–1280). That thinker combined with philosophical reflection on nature with wide-ranging empirical research.

The arrival of the period of the Renaissance was adumbrated by increased thought about nature. One must here mention: Cardinal *Nicholas of Cusa* (1401–1464), *Leonardo da Vinci* (1452–1529), *Giordano Bruno* (1548–1600), and above all *Francis Bacon* (1561–1626), who already knew that the epoch of the empirical sciences was at hand. However, the immediate cause of its arrival was not the assertions of some philosopher or other, but changes in the picture of the world which came about as a result of the development of the natural sciences. An important role in that process was played by the Copernican Revolution which drastically changed the way in which the world was seen.

The so-called *new physics*, originating in fourteenth century Oxford and maturing in the works of two professors at the University of Paris, Jean Buridan

(c. 1295–1358) and Nicholas Oresme (c. 1323–1384), prepared the way for Descartes. They made significant changes in the mechanics of Aristotle. It is not true that if an impulse does not act on a body, then the body does not move. A moving body has a certain impetus thanks to which it can still move for a certain time, after which the impetus is used up and the body assumes a state of rest. The significance of the theory of impetus is twofold: first, explicitly departing from an important principle of Aristotle's physics, it paved the way for further development; second, the departure from Aristotle was forced by experience, which paved the way for an ever greater influence of experiment on research into nature. But nevertheless the road was not easy. Before the rise of mechanics as a fully empirical science, the "philosophical mechanics" of Descartes had to see the light of day.

2 The Geometrical Mechanics of Descartes

At the foundations of the Cartesian philosophy of nature lie the mathematical achievements of its creator. René Descartes (1596–1650) discovered an effective method for transforming geometrical statements into algebraic equations.[1] The translation turned out to be equivalent. That fact created analytic geometry. Since the algebraic description of geometrical structures and the relations between them is more effective than manipulations with line and circle, the new branch of mathematics developed rapidly.

The possibility of applying analytical geometry to the description of natural phenomena was obvious to its creator. It was a qualitative novelty in relation to the physics of Aristotle. Although the calculative method (on the model of astronomy) became more and more frequent in medieval thought about nature, Cartesian geometry created entirely new possibilities. Now it was possible not only to make "calculations," but to propose mathematical descriptions with the aid of equations. The first candidate for such a description had to be phenomena connected with motion. But here the new method, in addition to showing various possibilities, showed a certain limitation: it is easy to describe the configuration of bodies geometrically, but it is significantly harder to do so for its evolution in time, i.e., for the very phenomenon of motion. The transition of bodies from one configuration to another has a discontinuous character. Physically, to that discontinuity corresponds impact. And that is why Cartesian mechanics is a mechanics of immediate contact: impact, friction, and vortices. It is a purely geometrical mechanics, without the concept of force, a mechanics in which there is no real dynamics.

Descartes formulated three principles (or laws) of mechanics, namely: 1. the law of inertia, 2. the law of rectilinear motion, and 3. the law of impact. But those are not yet the laws of mechanics known to us from introductory courses in physics. Descartes' *first principle* says only that:

[1] See *The Geometry of René Descartes*, trans. D. E. Smith and M. L. Latham (Chicago: Open Court, 1925).

> each thing . . . always remains in the same state as far as is in its power, and never changes except by external causes.[2]

The *second principle* says that bodies tend to rectilinear motion and that their trajectories deviate from rectilinearity only as a result of impact with another body. The *third principle* descriptively—but erroneously—presents the mechanics of the impact of two bodies. The source of the error is his lack of a well worked out concept of momentum.[3]

The geometrical view of mechanics led to a materialization of space in the Cartesian system. As we shall see, not only is extension the essence of material things, but empty space, unfilled with bodies, cannot exist. That conviction, in connection with his second principle of mechanics, led him to a surprising conclusion:

> no body can move except in a circle; in such a way that it drives another body out of the place which it enters, and that other takes the place of still another, and so on until the last, which enters the place left by the first one at the moment at which the first one leaves it.[4]

(And therefore the motion occurs with infinite speed!)

That reasoning was, of course, supposed to explain the circularity of planetary orbits. We have here a sample of the Cartesian "world machine," a machine powered by such a big dose of speculation that it overshadows the critical approach to the world that would allow one to see how the world works (or to carry out appropriate experiments).

The Cartesian philosophy of nature includes an idiosyncratic concept of time. It follows from his foundations of mechanics. Motion is measured by time. If motion is discontinuous and if the transition from one configuration of bodies to another has the character of a catastrophe, then that discontinuity is transferred to the nature of time. The claim about the discontinuous character of time was original to Descartes.

3 The Geometrical Mechanism of Descartes

Descartes did not feel the necessity of controlled experiments. He was too fascinated with his achievements in the field of geometry. The only criterion of truth is the "clarity and distinctness of cognition." That criterion is undoubtedly derived from the psychology of mathematical discovery. Descartes extended the criterion to all fields of knowledge, including physics and mathematics.

Descartes' physics remains closely connected with his metaphysics. It provides intuitions for metaphysical claims. Very often, those intuitions seem clear and distinct to Descartes, which—in accordance with his epistemology—frees him from

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[2]René Descartes, *The Principles of Philosophy*, II.37, trans. Valentine Rodger Miller and Reese P. Miller (Dordrecht: Reidel, 1983). Cited here with some slight simplifications.

[3]For more on this, see ibid., II.64–66.

[4]Descartes, *Principles*, II.33.

the need to search for any further justification. On the other hand, metaphysics assures physics of intelligibility; without it, physics would be left hanging in thin air, deprived of any fundamental rationality.

Descartes' physics cannot provide itself with that kind of rationality. For it is a physics of impact, and impact—understood in a Cartesian way—introduces, as we saw, a discontinuity between the configurations of the bodies before the impact and after it; what is more, it causes a discontinuity of time itself. Such a deep discontinuity is a gap in the rationality of physics—a gap which much be filled by a metaphysical justification.[5] That justification is the Cartesian claim that the world is constantly being created by God.

This claim, incorporated into a Cartesian system in which conclusions are deduced geometrically, leads immediately to consequences. The history of the world is a series of various configurations of bodies. The transition from one configuration to another is governed by the laws of impact. But a gap in rationality is also found at the beginning of the series of configurations. How can that first configuration be justified? Here also Descartes appeals to a creative act of God.

For creation provides physics with the rationality that it lacks. It does this in two stages—first, it grounds the initial state of the world: it is a *justification of the fact* (of the first configuration); second, it grounds the transition between particular configurations; it is a *justification of the law* (of the law of impact). Ladrière speaks here about the double contingency of the Cartesian world: the *contingency of fact* and the *contingency of law*.[6]

Let us note that the rationality which Descartes was seeking is a *mechanistic rationality*. The world is a kind of machine operating on principles of purely mechanical contact between its parts, and metaphysics is supposed to ensure the smooth operation of the machine. Cartesian mechanism is, however, a *geometrical mechanism*. What is more, Cartesian metaphysics looks like a *geometrical metaphysics* The concept of substance still plays a key role, but Descartes identifies substance with the spatial extension in of bodies. He writes:

> the nature of matter, or of body considered in general, does not consist in the fact that it is hard, heavy, colored, or affects the senses in any other way; but only in the fact that it is a thing possessing extension in length, breadth, and depth.[7]

The argument is fairly simple: A body can lose various traits (color, weight, ...), without ceasing to be what it is; but if it lost its extension, it would cease to exist at all.

In that way, substance was geometrized, and at the same time began to emerge the modern concept of matter as of something which can be touched, and therefore must be extended, something which resists our touch and acts on our senses.

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[5] See J. Ladrière, *Physique et Métaphysique.*

[6] Ibid.

[7] Descartes, *Principles*, II.4, trans. John Veitch.

4 In the Context of System

We must not, however, forget that Descartes' philosophy of nature is only a part of his philosophical system. The point of departure in his thought was undoubtedly mathematics (geometry), then came the turn of mechanics and the philosophy of nature, but the goal, of which Descartes never lost sight, was metaphysics. And one must not omit this aspect: the formulation of Descartes' philosophy of nature in a metaphysical context immediately reveals the fundamental flaw in his system and in some measure frees one from the necessity of further criticism. Mechanism as a philosophy of nature fails as a system; it leads to such a sharp dualism in metaphysics, that the whole philosophy is put into question.

The criterion of truth (the clarity and distinctness of knowledge) inevitably led Descartes to contemplation of his own internal states. *Cogito ergo sum* ("I think, therefore I am") was the first indubitable statement. But this statement concerns consciousness. How does one make the transition from the existence of a conscious spirit to the existence of spatially extended matter? Here Descartes chose a more roundabout way, but a way which in a net of conclusions internal to his system seemed to be unavoidable. That way led from the conscious self of the *cogito* through the affirmation of the contingency of his own consciousness, to an Absolute Being, i.e., God, and from God to the existence of the "external world" of spatially extended material bodies. God was necessary to Descartes as a guarantor of the veracity of human sense perception. Since God is the creator of our senses, they cannot delude us and therefore, "the external world exists."[8]

Here Descartes' dualism appears: conscious spirit and extended matter. The complete mechanism of Descartes breaks down on this metaphysical dualism. The laws of mechanics govern matter, but they do not extend to the sphere of spirit. The only factor integrating those two separated spheres is the method of inquiry. Both in the one sphere and in the other, inquiry must be conducted by deduction *more geometrico*. The weakness of the geometrical method in philosophy is based on the fact that, accepting the right premises, one can go wherever one wants. The new method of research into the world was left hanging in thin air. In the year in which Descartes died, Isaac Newton was eight years old.

Biographical Notes

Roger Bacon (c. 1214–1292), philosopher and English scientist. He probably studied under Robert Grosseteste at Oxford (1229–1235). He left for Paris, where he was one of the first to read Aristotle and to write commentaries on him. In 1247 he returned to Oxford, where he studied various sciences—among others he devoted much attention to optics—and valued empirical research. In 1257, he entered the

[8]For more on Descartes' views, see, for example, Ferdinand Alquié, *Descartes* (Paris: Hatier, 1956).

Franciscan Order. Bacon strove for a reform of Christian education. He laid out his views on this topic in his work, the *Opus maius*, and also in two smaller works, the *Opus minus* and the *Opus tertium*. One can also count his *Communia mathematica* [*The General Principles of Mathematical Science*] and the *Communia naturalium* [*The General Principles of Natural Philosophy*] as scientific writings. We also find references to Bacon's interests in alchemy and astrology, which was supposed to have led to a condemnation of his doctrine by Jerome of Ascoli, general of the Franciscan Order.

St. Albert the Great (1193–1280), philosopher and scientist. He was born in Lauingen, and studied in Padua and Bologna. During his philosophical studies in Padua in 1233, he entered the Dominican Order. He taught in Cologne and then at the University of Paris, where Thomas Aquinas was his student. In 1248 he returned to Cologne and in 1260 he was consecrated bishop of Regensburg. After 2 years he resigned as bishop and returned to teaching at the Dominican house of studies in Cologne. Albert the Great is considered to be one of the most versatile scientists of the Middle Ages. He combined his philosophical and theological interests with the study of nature and had enormous importance in the history of biology. In 1931, he was proclaimed a saint by the Catholic Church and was made patron of the natural sciences.

Giordano Bruno (1548–1600), prominent representative of Renaissance philosophy of nature. He was born in Nola, near Naples. In 1563, he entered the Dominican Order. He doubted the truth of many dogmas of the faith, which led in 1576 to his condemnation for heresy, after which he fled the order. He wandered about Europe for many years. Toulouse, where he taught as professor of philosophy for 2 years, Paris, where he was active at the university, and Oxford and London, where his main works appeared, are above all associated with his scientific work. After his return to Italy in 1592, he was arrested by the Inquisition and put before a judge in Venice. After a long trial he was sentenced to death for the beliefs which he expressed about Catholic dogmas. He was burned at Rome in 1600. The most important of Giordano Bruno's works were *Della causa principio et uno* [*Concerning Cause, Principle, and Unity*] and *Dell'infinito universo e mondi* [*On the Infinite, the Universe and the World*].

René Descartes [Cartesius] (1596–1650), French mathematician, scientist, and philosopher. He was born in the province of Touraine. He attended the Jesuit college of La Flèche and studied law at the University of Poitiers, though he never worked as a lawyer. After his studies, he traveled for many years through Europe. In 1618, under the influence of the mathematician Isaac Beeckman, he began to study mathematics. That study bore fruit in his creation of the foundations of analytic geometry. In 1628, Descartes moved to Holland, where for 20 years he devoted himself to scientific work. There he worked on his book *Le Monde* ("The World"), in which he included his mechanistic interpretation of the universe. After Galileo's condemnation, Descartes decided to withhold the book from publication. Among the other writings of Descartes we find *The Discourse on Method*, *Meditations on First Philosophy*, and *The Principles of Philosophy.* All those works were supposed to lay the groundwork for *Le Monde*. However, not longer after taking up the position of court philosopher to the Swedish Queen Christina, Descartes died and *Le Monde* was published only after his death.

Appendix: The Philosophy of Nature from the Middle Ages to Modern Times

Since our book concentrates on the most important "episodes" in the history of philosophy in science, it is worthwhile here, even if briefly (and necessarily very selectively) to fill the gap which arose in our transition from antiquity to Descartes.

1. The twelfth century was, for medieval philosophy, a period of particular significance. It became such as a result of the *renaissance of ancient culture* in a new form after its encounter with Christian culture. The *school of Chartres* had a particular importance for the philosophy of nature. In that school, philosophy was conducted in a *Platonic* spirit; from it, two names stand out in the history of philosophy—Theodoric of Chartres and William of Conches. Let us have a look at their beliefs about structure of the world.

   - *Theodoric of Chartres* asserted that the matter of the universe is composed of the traditional "*four elements*" and all processes can be explained by the operation of *forces* (*virtutes*). God was believed to take part in the creation of the world, but Theodoric also ascribed a particular role to physical forces. Theodoric interpreted the Biblical picture of the creation of the world found in the Book of Genesis naturalistically. Fire played a particular role in the emergence of the world; it was the cause of motion and even—as Theodoric writes—its artificer and efficient cause.
   - *William of Conches* in his work entitled *Philosophia mundi* (*The Philosophy of the World*) constructed a theory of the "four elements," but in addition to them he accepted very small, invisible, atom-like *material particles*. William explained the phenomena of nature as a transition from one mixture of elements and material particles to another mixture. In addition to that, he believed that natural forces were operative in nature.

   The school of Chartres developed a new way of thinking about nature, a departure from seeing the world as a *symbol* referring directly to the Creator (e.g., in St. Augustine, the world was understood as a *vestigium Dei*—a trace of the Creator). Theodoric and William began a tradition of *naturalism* in which the phenomena of nature are explained by appeal to nature itself.
2. *Roger Bacon* and the *Oxford* school occupy a special place in medieval philosophy. Roger Bacon deserves particular notice not so much for his stated views about nature as for the *methodology* he elaborated. Bacon was an adherent to

the Aristotelian inductive-deductive method, but he placed particular emphasis on the *inductive phase*, claiming that it is the inductive phase that determines to what extent our knowledge is based upon facts. The Oxford philosopher gave particular weight to the problem of *experience* and *experiment*, In his writings, there appears for the first time a distinction between *ordinary* and *scientific* experience. The latter is characterized by the fact that it is conducted with the help of equipment and of the use of mathematical techniques.

3. As we recall, the thirteenth century brought a return to Aristotelianism. This was caused chiefly by Albert of Lauingen, known as *Albert the Great.* In addition, Albert is known as the most prominent *scientist* of the Middle Ages. On the basis of his research, he prepared, among other things, a classification of plants and animals. He also studied logic, developing a system based on the logic of Aristotle. From the time of Albert the Great, the philosophy and the science of the Middle Ages was distinctly *Aristotelian.*
4. The period of the *Renaissance*, which was not perhaps a time of particular accomplishments in the field of philosophy, became for science an important point on the road to *modern rationalism.* One could take 1543 as the date of most importance in Renaissance science, the year in which Nicholas Copernicus published his work against the ancient and medieval geocentrism which had been consolidated in the second century by Ptolemy. The recognition that the sun, and not the earth, is the immovable center of our world eventually forced the acceptance of a new picture of reality and bore fruit in new philosophical currents which could not have appeared before the "astronomical revolution."

   Among Renaissance philosophers of nature of particular significance are Giordano Bruno and Francis Bacon, the first as the author of a new picture of the world and the second as the author of new methodological ideas.

- *Giordano Bruno*, proponent of Copernicanism, departed from Aristotelian doctrine in his recognition that the world is *infinite*. Man, considering the limitation of his intellectual powers, has access only to a finite part of it. Bruno also advanced the thesis—revolutionary for those times—that there is no center of the world: since the world is infinite and, what is more, homogeneous and does not contain distinct places, any place can be taken as its center. Bruno presented a theory of the *monads* (from the Greek word *monas*—unit), the smallest (metaphysically understood) units of the world. Monads are formed by God. In Bruno's philosophy, what is important is his *anti-mechanism*. The world is not governed by mechanical laws, but lives according to laws of its own—and every part of the world, even the smallest, has its own soul. A clear opposition to that position develops only in the seventeenth century, when all processes were taken to be elements in the operation of the great world-machine.
- *Francis Bacon*, living at the end of the Renaissance, became famous most of all as a critic of Aristotelian methodology, which was developed particularly in the Middle Ages. His chief work, the *Novum Organum*, was supposed to replace the medieval *Organon* which had been based almost entirely on

the writings of Aristotle. Bacon did not completely reject the method of the Stagirite; he recognized, however, that that methodology required many corrections. Bacon emphasized two aspects of the "new" method: the necessity of gradual, progressive *induction* and the application of the *principle of exclusion*. The inductive process was supposed to depend not only on the collection of facts, but also on a search for correlations between facts and on a gradual transition ever more general conclusions. The principle of exclusion was, in turn, supposed to eliminate those correlations between facts which are not important. Bacon also emphasized the importance to science of cooperation in research among scientists.

5. The turning point for philosophy in science was the *mechanistic* philosophy of Descartes. Even though his system of mechanics was incoherent and intuitive, and was forced in the end to yield to the mechanics of Newton, his philosophy left traces in modern European thought. With respect to *methodology*, Descartes opposed the Baconian method of induction and postulated that by means of deduction one can get from general statements which are certain to particular statements. *Reverse induction* had as its goal emphasis on the fact that man is capable of making discoveries which are not subject to doubt—since "I think," therefore I must exist and God, as the warrant of all certainty, must exist also. Let us now look at the most important aspects of Descartes' philosophy of nature, which contributed much to the development of European philosophy.

   - *Dualism*—extended *matter* and conscious *spirit*—is the fundamental cleavage in Cartesian system. Of course, the consequences of that cleavage impressed themselves on Descartes' mechanics, since that mechanics was limited only to the external world. That cleavage had great significance for the development of philosophy itself. Descartes was the first to turn his attention to the difference which exists between the "external world" and that which can be called the "internal world." The impossibility of eliminating the *ontological gap* between those worlds, led to the emergence of two schools—on the one hand there appeared a *science* whose task was the investigation of the material world; on the other hand—*philosophy*, concerned with the internal world of the "thinking I." The term "philosophy" here was used in one of many possible meanings, as the philosophy of the subject. Descartes understood philosophy in this very way. The "*philosophy of the subject*" is a school which has continued until today. At its foundations is the conviction that thought begins with a question about the "I" as the subject of all experience. The most eminent representative of that school of philosophy was Immanuel Kant. The emergence of the philosophy of the subject and, at the same time, the removal of man and his consciousness from the field of the natural sciences, can be seen as the beginning of the existence of modern philosophy and the modern empirical sciences as two separate fields of knowledge.
   - The *concept of matter* gained a particular significance in the philosophy of Descartes. In ancient and medieval philosophy, it was not sharply defined and was usually associated with Aristotelian prime matter. Descartes, to meet

the needs of his system, identified the concept of matter with the concept of *extension*. Extension is the only irremovable feature of matter, without which it cannot be thought of, and all its properties, e.g., shape, color, and weight, result from the fact that matter is divisible and its parts are subject to motion. Matter, thanks to Descartes, became something concrete, tangible, and visible. That gave it a characteristic of reality in contrast to the abstract concept of matter which functioned in earlier centuries.

- It is worth turning our attention to the fact that the Cartesian *principles of mechanics*, despite the fact that they contained errors, were not abandoned as soon as Newton's mechanics appeared. Cartesianism was a rival of the Newtonian system not so much for substantive reasons as for psychological ones. Its *intuitive* character gave it a feeling of simplicity and evidence, making it more intelligible, and not only for scientists. The conceptions of Descartes had these features, that they concerned almost all the phenomena that one can observe in nature. Thus, Cartesian mechanics allowed the creation of a comprehensive picture of the world, starting with the problems of geology, through physics, chemistry, astronomy, and cosmology, and ending in medicine. Descartes combined in his system two seemingly completely opposed elements. On the one hand, he described an extraordinarily complicated *world-machine*; on the other—he chose as a tool of inquiry a simple (not to say, naïve) methodology based on the intuitive criterion of *clarity* and *distinctness*. Despite its doubtful scientific value, it proved to be very attractive, because it made it relatively easy to obtain a coherent picture of the world, freed from any unclarity.

Chapter 6
Isaac Newton and the Mathematical Principles of Natural Philosophy

1 Introduction: Towards a New Method

The appearance of *Isaac Newton*'s (1642–1727) *Principia Mathematica Philosophiae Naturalis* (*The Mathematical Principles of Natural Philosophy*) in 1687 is taken symbolically as the beginning of the new era of the empirical sciences. Newton's work laid the foundations for the first part of the new physics—classical mechanics. Was that also a revolution for philosophy in science? The title of Newton's main work indicates that he himself regarded his achievements as important for philosophy. Subsequent generations read the *Principia* through the prism of mechanism. In Newton, they saw someone who had put an end to the speculative philosophy of nature and had begun the scientific, as opposed to the philosophical, study of the world. After the fall of mechanism, it was said that although Newton was a philosopher of nature, his philosophy of nature was false. Absolute time and absolute space do not exist. The world is not deterministic and it is not governed by the laws of mechanics; one can take them only as good approximations at the level of ordinary objects.

Such an interpretation of Newton's work is an unacceptable oversimplification. In the first place, Newton did practice a speculative philosophy of nature. The distinction between the mathematico-empirical layer and the layer of philosophical inquiry is fairly explicit in his works. Newton was aware of the novelty and the importance of the first layer, but he valued the second layer more. He considered the philosophical discovery of the causes of the laws of nature established by the mathematico-experimental method to be the ultimate end of science. Neither can one say that the Newtonian philosophy of nature is no longer of any significance. Even though many of Newton's positions can no longer be maintained, the influence of his work on all modern philosophical thought about nature cannot be overestimated. That influence stems, above all, from the mathematico-empirical method, a method of studying the world, to which Newton gave, if not its final, at least its essential form. This method has not only "technical" aspects—it leads effectively to desired results, but it also has authentically philosophical aspects: it defines a completely new relation between man as researcher and nature and it provides a qualitatively new kind of information about nature, information which creates, from that time forward, a necessary context for any type of intellectually responsible reflection about nature.

Of course, the appearance of a new method of inquiry into nature was not an ahistorical process. The new method was the result of a long process of development in philosophical thought about nature, a development which became more rapid in the later Middle Ages and at the beginning of the modern period. As we saw in the previous chapter, Descartes was of great significance for that process. However, when one speaks about that new method, one must not forget Bacon and Galileo.

Francis Bacon (1551–1626) became a theoretician of the empirical method before it arose. There is nothing surprising in the fact that his theory deviated significantly from later practice. Bacon was able to foresee that an empirical method would be necessary for the decipherment of nature, but identified it with the inductive method, i.e., roughly speaking, with a procedure that followed the format: from many examined "particular instances" to a general conclusion. Bacon "invented" the new method on the basis of opposition to traditional philosophical speculation (in which, according to him, deduction reigned: from a general statement to particular instances), rather than from actual practice with the new method.

That practice was rather the work of *Galileo* (1564–1642). His reflection about the empirical method were the result of its practical applications in the works which launched modern mechanics. Above all, Galileo was the first explicitly to understand that experience must be connected to a mathematical formulation. The connection between experiment and mathematics is measurement, which translates the result of experience into the language of mathematics. Mathematics not only provides infallible links in a chain of reasoning, it does something much more important: "The book of nature is written in the language of mathematics." In that statement of Galileo, especially when it is placed in the context of his research, there is a note of his conviction that the structure of the world has much in common with the structure of mathematics.

The effectiveness of mathematics displaces the laborious collection of data in accordance with the inductive suggestions of Bacon. Often one bold conjecture and a thought experiment based on it, or the idealization of a complicated phenomenon and its skillful placement into a chain of mathematical reasoning, make possible the achievement of a result which would have remained inaccessible with the Baconian method.[1]

There is disagreement about whether it is Galileo or Newton who should be considered the creator of classical mechanics and the inventor of the mathematico-empirical method. I think that any resolution of that disagreement would have to be made more or less arbitrarily. The mathematico-empirical method of inquiry is not the work of any one man. Its roots reach (at least) to the earliest questions about

[1] For more on the topic of Galileo's method, see the many works in the volume, *Galileo—Man of Science*, ed. Ernan McMullin (New York: Basic Books, 1967); there are also interesting comments in J. M. Życiński, "Why Galileo's Research Program Superseded Rival Programs" in *The Galileo Affair: A Meeting of Faith and Science*, ed. G. V. Coyne, M. Heller, and J. M. Życiński (Vatican City: Specola Vaticana, 1985), 137–148.

arche. I am treating Newton and his work *The Mathematical Principles of Natural Philosophy* rather as a symbol of the new epoch and of the new method.

This chapter will have a different character from the previous ones. In place of a more or less synthetic presentation of the entirety of Newton's views, we will concentrate on reading a few passages from his *Principia* concerning, above all, his thoughts on the "new method."[2] For the reasons I gave above, I think that those passages are a turning point for philosophy of science in Europe, and their importance and role in world culture is no less important than such works as Plato's *Timaeus* and Aristotle's *Physics*.

In Newton's *Principia*, there is a rich layer of philosophy. Some of Newton's philosophical views will be mentioned in the discussion of his methodology; I will offer a direct treatment only of his doctrine of the absoluteness of space and time. That doctrine exerted such a great influence on succeeding generations, that to omit it would be a distortion of Newton's thought. In this part of the chapter, I will make use of the tactic of citing long fragments of the original texts and of providing the necessary commentary.

2 Newton's Introduction to the *Principia*

The introduction which Newton wrote to the first edition of *The Mathematical Principles of Natural Philosophy* is a short text (about three pages in length), but one which raises important topics: it speaks, namely, about the relation of the new mechanics to mathematics, and more precisely, to geometry and about the significance of mechanics for the philosophy of nature. Nowhere in this text does Newton call his mechanics new: In both the sphere of empirical research and in that of philosophical inquiry, he thinks of himself as continuing a tradition. Here is the beginning of his introduction:

> Since the ancients (as we are told by Pappas), made great account of the science of mechanics in the investigation of natural things; and the moderns, laying aside substantial forms and occult qualities, have endeavoured to subject the phænomena of nature to the laws of mathematics, I have in this treatise cultivated mathematics so far as it regards philosophy. The ancients considered mechanics in a twofold respect; as rational, which proceeds accurately by demonstration; and practical. To practical mechanics all the manual arts belong, from which mechanics took its name. But as artificers do not work with perfect accuracy, it comes to pass that mechanics is so distinguished from geometry, that what is perfectly accurate is called geometrical; what is less so, is called mechanical.[3]

[2] Of course, a more complete understanding of "Newton's method" is not possible without a familiarity with the rest of his views; therefore I would very much like the reader to take a look at the corresponding literature: for example, I. Bernard Cohen and George E. Smith, eds., *The Cambridge Companion to Newton* (Cambridge, 2002), or either of two works by Richard S. Westfall—*Never at Rest* (Cambridge, 1981) and *Isaac Newton* (Cambridge, 2007).

[3] Sir Isaac Newton, *Principia Mathematica Philosophiae Naturalis*, trans. A. Motte (Berkeley: University of California Press, 1962), 1, xvii.

Here we encounter a common-sensical and universally reigning philosophy of geometry (or in general of mathematics). Geometry is a science of the real world, namely, about the spatial relations which occur in the world, and differs from other experiential sciences only in the fact that it goes to the extreme in the idealization of the object of its investigations. The relaxation of the rigor of idealization leads to mechanics. The errors, however, are located not in the art, but in the artisans.

Today we would say that each measurement is laden with unavoidable measurement errors and, wanting to treat description realistically, we must allow for a certain inexactitude. But Newton thinks much more geometrically. According to him:

> . . . the description of right lines and circles, upon which geometry is founded, belongs to mechanics. Geometry does not teach us to draw these lines, but requires them to be drawn; . . . To describe right lines and circles are problems, but not geometrical problems. The solution of these problems is required from mechanics; and by geometry the use of them, when so solved, is shown.[4]

That passage can be understood as follows:

Mechanical knowledge has to do with the material world. That world "is geometrical." By way of abstraction from material things we come to a formula telling us how to construct ("draw") geometrical figures ("lines and circles"). Our constructive formulations are based on the idealization of real situations. And this is where geometry begins. Newton showed a great metaphysical intuition when he wrote:

> it is the glory of geometry that from those few principles, brought from without, it is able to produce so many things.[5]

The context indicates that the "principles, brought from without" (sc., from outside geometry) are the construction formulae which mechanics provides. Newton thought that those principles did not belong to geometry itself. If the statement is understood as saying that geometry itself does not justify its own axioms, then it sounds very modern. Less modern and more Newtonian is the interpretation of mechanics as the foundation for geometry.

> Therefore geometry is founded in mechanical practice, and is nothing but that part of universal mechanics which accurately proposes and demonstrates the art of measuring.[6]

Then what does the difference between mechanics and geometry come to? Here is Newton's answer:

> But since the manual arts are chiefly conversant in the moving of bodies, it comes to pass that geometry is commonly referred to their magnitudes, and mechanics to their motion.[7]

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[4] Ibid.

[5] Ibid.

[6] Ibid.

[7] Ibid.

What follows next is the classical definition of mechanics (classical because repeated in many textbooks):

> In this sense rational mechanics will be the science of motions resulting from any forces whatsoever, and of the forces required to produce any motions, accurately proposed and demonstrated.[8]

The latter (the method of accurate propositions and demonstrations) assimilates "rational mechanics" to geometry.

It is characteristic that Newton devoted the beginning of his introduction to the *Principia* precisely to a discussion of the relation of mechanics to geometry. It is undoubtedly an echo of Descartes' requirement to practice mechanics *more geometrico* (and therefore the demand for a geometrization of mechanics).[9] But there is also something more. Newton—despite the fact that he himself laid the foundations for mathematical analysis, which, in his writing, was already beginning to displace the traditional geometrical methods in the study of nature—followed the example of the authors of antiquity and identified mathematics with geometry. The problem of the relation of mechanics to geometry was for him basically a case of the problem of the relation of nature to mathematics in general. The creator of classical mechanics tried to understand the sense in which "the book of nature is written in the language of mathematics." Newton's arguments—as we saw—did not give a complete answer to the question "in what sense?" but affirmed forcefully that the structure of nature is mathematical. And it is just for that reason that geometry can be derived by abstraction and idealization from real structures present in nature.

After examination of the relation of mechanics to geometry, Newton considered the relation of mechanics to philosophy. In his opinion, the ancients practiced mechanics, but as a manual art while he treated it as philosophy.

> Our design not respecting arts, but philosophy, and our subject not manual but natural powers, we consider chiefly those things which relate to gravity, levity, elastic force, the resistance of fluids, and the like forces, whether attractive or impulsive; and therefore we offer this work as the mathematical principles of philosophy; for *all the difficulty of philosophy seems to consist in this–from the phænomena of motions to investigate the forces of nature, and then from these forces to demonstrate the other phænomena*.[10]

Newton calls the work which became the first work of modern physics philosophy. With that spark of genius, Newton also establishes the method of a new science. Despite what many later thinkers have said, his method is not induction in the sense usually ascribed to Bacon. (In fact, Bacon's idea of induction was much more sophisticated). There is here no simple enumeration of many empirical results and a drawing from them of a general conclusion. The point of departure is experience (the phenomena of motion), but immediately afterwards comes a theoretical

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[8] Ibid.

[9] Alexandre Koyré, *Newtonian Studies* (London: Chapman & Hall, 1965), Chap. 4, thinks that Newton's most important work is a polemic against Descartes; the very choice of the title *The Mathematical Principles of Natural Philosophy* refers to Descartes' *The Philosophy of Nature*.

[10] Newton, *Principia*, xvii–xviii. Emphasis mine.

construct (inquiry into the forces of nature). The whole process of investigation is supposed to end with the prediction of new phenomena ("to demonstrate the other phænomena").

Is Newton's *Principia*, or is it not, a philosophical work? McMullin[11] distinguishes three layers in the *Principia*: 1. the *mathematical*: analyses of the consequences following from the laws of nature with the help of the methods of mathematics, 2. the *physical*: the establishment of which laws hold *de facto* in nature, 3. the *philosophical*, whose end is supposed to be an inquiry into the causes of the forces present in nature. Newton himself placed great weight on the third layer and thought that the success of future science would concern that sphere above all.

Later in his introduction, Newton writes, that the first two books of his *Principia* realize his plan for a mathematical philosophy of nature. Let us recall that the first book begins with the famous "definitions" which are a brief summary of Newton's views concerning motion, space, and time; next comes an exposition of his "principles of motion," among which are found Newton's three "laws of motion." The second book is an application of the general principles to various particular cases (the mechanics of fluids, wave motion, etc.). In his introduction, Newton presents the third book in more detail as follows:

> In the third book we give an example of this in the explication of the System of the World; for by the propositions mathematically demonstrated in the former books, we in the third derive from the celestial phænomena the forces of gravity with which bodies tend to the sun and the several planets. Then from these forces, by other propositions which are also mathematical, we deduce the motions of the planets, the comets, the moon, and the sea.[12]

From that statement, one can see that, for Newton, the "System of the World" is limited to the planetary system.

Newton is without a doubt impressed by his own achievements. The results he attained give him good reason to believe that he is on the right path.

> I wish we could derive the rest of the phænomena of nature by the same kind of reasoning from mechanical principles; for I am induced by many reasons to suspect that they may all depend upon certain forces by which the particles of bodies, by some causes hitherto unknown, are either mutually impelled towards each other, and cohere in regular figures, or are repelled and recede from each other; which forces being unknown, philosophers have hitherto attempted the search of nature in vain; but I hope the principles here laid down will afford some light either to this or some truer method of philosophy.[13]

That passage can be read as a kind of declaration of mechanism: reduction to mechanical principles is supposed to be the only effective explanation, but Newton is much more careful and much more far-seeing than his immediate successors. A close reading of the text cited above makes it possible to interpret it, for example, in the spirit of contemporary field theories. Even today, physicists try to identify

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[11]See Ernan McMullin, *Newton on Matter and Activity* (Notre Dame: University of Notre Dame Press, 1978), 2.

[12]Newton, *Principia*, xviii.

[13]Ibid.

the forces (interactions) responsible for the observed configurations of particles. Of course it is necessary to take into consideration the fact that, from the time of Newton, the concepts of particle, interaction, etc. have undergone drastic transformations. The evolution of the concepts is an essential element of the evolution of science.

The last paragraph of the introduction contains expressions of gratitude to Edmund Halley for his encouragement to write the *Principia* and later for his active help in the course of the execution of the project. Halley initially insisted that Newton write down his conclusions about the shape of the orbits of heavenly bodies under the influence of a force of gravity. In the course of carrying out this project, Newton began to notice more fundamental problems and to ponder them.

> I deferred that publication till I had made a search into those matters, and could put forth the whole together.[14]

Great works sometimes arise as the side effects of less ambitious intentions.

The introduction ends with an appeal to the reader:

> I heartily beg that what I have here done may be read with candour; and that the defects in a subject so difficult be not so much reprehended as kindly supplied, and investigated by new endeavours of my readers.[15]

3 Rules of Reasoning in Philosophy

Under that heading, in Book III of the *Principia* Newton lists and comments on principles by which he recommends that research into nature should be guided:

> Rule I: *We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.*—To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp of superfluous causes.[16]

The principle of simplicity had been applied in the philosophy of nature for a long time. It is worth noting the opposition: cause–appearance. With time, there was a consolidation of the conviction, to which Newton himself to some extent contributed, that only the world of appearances is accessible to the empirical sciences.

> Rule II: *Therefore to the same natural effects we must, as far as possible, assign the same causes.*—As to respiration in a man and in a beast; the descent of stones in Europe and in America; the light of our culinary fire and of the sun; the reflection of light from the earth, and from the planets.[17]

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[14] Ibid.

[15] Ibid.

[16] Ibid., 2: 398. Emphasis Newton's.

[17] Ibid. Emphasis Newton's.

Along with the empirical sciences arises a conviction about the unity of nature. In the future it will have many incarnations and realizations, but a broadly understood idea of the unity of the world would have to be recognized as an assumption of the empirical method.

Newton's first two rules have deep roots in the traditional philosophy of nature, which always considered itself to be a science of the causes of the world. We notice that Rule II speaks of the direction of reasoning from effect to cause. Methodologists later called that method of reasoning retroductive reasoning.

> Rule III: *The qualities of bodies, which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever*.[18]

In the commentary on that rule, Newton lists as universal qualities of that kind: in the first place—extension, and later: hardness, impenetrability, mobility, and inertia. He emphasized that we find out about the existence of those qualities from experience ("We are certainly not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising") and that it is the source of our certainty.

> The extension, hardness, impenetrability, mobility, and *vis inertiæ* of the whole, result from the extension, hardness, impenetrability, mobility, and *vires inertiæ* of the parts; and thence we conclude the least particles of all bodies to be also all extended, and hard and impenetrable, and moveable, and endowed with their proper *vires inertiæ*. And this is the foundation of all philosophy.[19]

In fact, that conviction became a dogma of the mechanistic philosophy. How very false it is we can determine only from the perspective of today's quantum mechanics and quantum electrodynamics. Although in the mathematical and physical layer of Newton's work, the concept of matter (as non-operationalizable) was effectively eliminated (although Newton himself did not realize this) and was replaced with other concepts (such as mass or density, which can be directly measured), but in the philosophical layer that concept still played a fundamental role. Newton defined matter as the substrate of universal qualities[20]:

In connection with the universal qualities arises the problem of gravitation. On the basis of Newton's results, and of his methodological principles, the universality of gravitation was not open to doubt.

> . . . we must, in consequence of this rule, universally allow that all bodies whatsoever are endowed with a principle of mutual gravitation. For the argument from the appearances concludes with more force for the universal gravitation of all bodies than for their impenetrability; of which, among those in the celestial regions, we have no experiments, nor any

[18] Ibid. Emphasis Newton's.

[19] Ibid., 2: 399.

[20] At this point in Newton's commentary on Rule III, there occurs a long argument on the topic of whether the smallest particles of bodies can be effectively divided into ever smaller parts to infinity.

> manner of observation. Not that I affirm gravity to be essential to bodies: by their *vis insita* I mean nothing but their *vis inertiæ*. This is immutable. Their gravity is diminished as they recede from the earth.[21]

Newton's hesitation about whether gravity is "essential to bodies" has a deep source. According to a tradition reaching back to Aristotle, matter should be passive. Meanwhile, gravitation could be understood as a manifestation of the activity of matter. Newton did not want to depart from that tradition. He hesitated and changed his mind on that question many times.[22]

> Rule IV: *In experimental philosophy we are to look upon propositions collected by general induction from phænomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phænomena occur, by which they may either be made more accurate, or liable to exceptions.*[23]

The purpose of the rule—according to Newton—is the safeguarding of those empirical results (achieved by "induction") from the invention of hypotheses. Only new experience can change such conclusions. Openness to the revision of one's conclusions under the pressure of new experience is a Newton's own deep convictions feature of the empirical method. It is possible to discern here an echo of the principle of falsification.

4 The Scholium

As I mentioned above, the evolution of concepts is an important element in the history of science. Concepts ripen slowly, sometimes over the course of centuries. Experiences begin to take on significance only when they begin to resonate with a set of sufficiently meaningful concepts; without a properly developed system of concepts, a well-functioning theory cannot emerge. In Book I of Newton's *Principia*, there is a chapter entitled "Definitions and Scholium." The definitions establish the conceptual apparatus of a new mechanics; their precise expression became the necessary condition of Newton's success. They define the meaning of such terms as: quantity of matter, i.e., mass; quantity of motion, i.e., momentum; inertia; force; etc. The characteristic feature of these definitions is their *operationalizability*: each definition contains a rule for the measurement of the corresponding quantity. Newton's definitions are repeated in almost all physics textbooks, though in various linguistic formulations, even today.

After the definitions, comes the Scholium, i.e., a kind of supplement. Newton's brilliant insight was to divide operational concepts, indispensable to the development of mechanics itself, from those concepts which are located, as it were, in the philosophical background of physics and which can be defined only by more or

[21] Newton, *Principia*, 2: 399–400.

[22] See Ernan McMullin, *Newton on Matter and Activity*.

[23] Sir Isaac Newton, op. cit., 2: 400.

less descriptive explanations. The Scholium presents, in compact form, elements of an interpretation which Newton himself gave to the mechanics which he created. In what follows, I cite only a few of the most important fragments of the Scholium. Here is how it begins:

> Hitherto I have laid down the definitions of such words as are less known, and explained the sense in which I would have them to be understood in the following discourse. I do not define time, space, place and motion, as being well known to all. Only I must observe, that the vulgar conceive those quantities under no other notions but from the relation they bear to sensible objects. And thence arise certain prejudices, for the removing of which, it will be convenient to distinguish them into absolute and relative, true and apparent, mathematical and common.[24]

And so, the fragments which follow are not—despite a common misconception—definitions. Definitions are superfluous when everyone knows the relevant concepts. The passages in the Scholium are only explanatory descriptions, the main goal of which is the introduction of precising distinctions.

> I. Absolute, true, and mathematical time, of itself, and from its own nature flows equably without regard to anything external, and by another name is called duration: relative, apparent, and common time, is some sensible and external (whether accurate or unequable) measure of duration by the means of motion, which is commonly used instead of true time; such as an hour, a day, a month, a year.

> II. Absolute space, in its own nature, without regard to anything external, remains always similar and immovable. Relative space is some movable dimension or measure of the absolute spaces; which our senses determine by its position to bodies; and which is vulgarly taken for immovable space; such is the dimension of a subterraneous, an æreal, or celestial space, determined by its position in respect of the earth. Absolute and relative space, are the same in figure and magnitude; but they do not remain always numerically the same. For if the earth, for instance, moves, a space of our air, which relatively and in respect of the earth remains always the same, will at one time be one part of the absolute space into which the air passes; at another time it will be another part of the same, and so, absolutely understood, it will be perpetually mutable.[25]

Thus, therefore, the distinction between absolute and relative time and space is clear enough: absolute time and absolute space correspond to that, which time and space "really" are, while relative time and relative space are only "measures" of absolute time and absolute space.

Absolute time and absolute space have the character of objects (existing "without regard to anything external"). No physical processes have an influence on the structure of absolute time and absolute space. (Absolute) time and space are a rigid stage and do not take part in the drama of physics, as it plays itself out on that stage.

Relative time and relative space, as some kinds of "measures," have the status of a system of relations: our senses determine relative space and relative time "by [their] position to bodies" or by motion.

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[24] Newton, *Principia*, 1: 6.

[25] Ibid., 6–7.

> III. Place is a part of space which a body takes up, and is according to the space, either absolute or relative. I say, a part of space; not the situation nor the external surface of the body. For the places of equal solids are always equal; but their superfices, by reason of their dissimilar figures, are often unequal.[26]

In the definition of place, which—as we shall see—is a kind of mediating link between the definition of space and the definition of motion, and one can clearly hear a note of polemics against the definition of place offered by Aristotle. It is precisely Aristotle who had defined the place of a body with the help of the surroundings in contact with the surface of that body. Newton's absolute space fulfills the function of "universal background," but does not require any surroundings for the placement of the body.

> IV. Absolute motion is the translation of a body from one absolute place into another; and relative motion, the translation from one relative place into another.[27]

According to Newton, the proof of the absoluteness of motion is the presence of inertia. If in some system of reference (e.g., that of a stagecoach) forces of inertia appear (suitcases fall), that means that the system underwent acceleration with reference to absolute space, i.e., it is the system which moves with absolute motion, and not its surroundings (the stagecoach moves forward, and not the earth backwards).

Newton here analyzes in great detail his famous experiment with a rotating bucket suspended from a twisted rope. The concavity that forms on the surface of the water in the bucket provides evidence of the absolute rotation of the bucket and the water. It is not the universe that is moving in the opposite direction.[28]

Nevertheless, Newton was well aware of the problems associated with the postulation of "absolutes." Here is what he writes about such difficulties in connection with absolute space:

> But because the parts of space cannot be seen, or distinguished from one another by our senses, therefore in their stead we use sensible measures of them. For from the positions and distances of things from any body considered as immovable, we define all places; and then with respect to such places, we estimate all motions, considering bodies as transferred from some of those places into others. And so, instead of absolute places and motions, we use relative ones; and that without any inconvenience in common affairs; *but in philosophical disquisitions, we ought to abstract from our senses, and consider things themselves, distinct from what are only sensible measures of them.* For it may be that there is no body really at rest, to which the places and motions of others may be referred.[29]

The statement which I highlighted in the passage just quoted shows how very philosophically Newton understood his decision "not to feign hypotheses" (Newton's famous *hypotheses non fingo*). It was not possible for Newton to impose

[26] Ibid., 7.

[27] Ibid., 7.

[28] Newton's experiment and its interpretation have a long history. Mach later analyzed it in detail; Einstein also made reference to it. Mach argued that the concavity could be the result of the bucket's motion relative to the distribution of matter in the universe rather than relative to absolute space.

[29] Newton, *Principia*, 1:8.

later positivistic views.[30] For him, the existence of absolute time, space, place, and motion was not only not an hypothesis, but was an intellectual necessity, and indispensable presupposition which justified the function of "sensible measures," i.e., relative space, time, place, and motion which must be used in physical practice.

The Newtonian interpretation of classical mechanics presented in his Scholium had an overwhelming influence on the future of philosophy in science. With time, it became a part of the mechanistic interpretation of the world.

One can put here a rather unexpected question: Whether Newton's interpretation of his mechanics is correct? The answer to that question became possible only after the emergence of the modern methods of differential geometry (worked out in large measure to meet the needs of the theory of relativity). It turns out that the structure of classical mechanics really requires the existence of absolute time (i.e., absolute time is a part of its structure), but it does not require, nor does it even permit, the existence of absolute space (and therefore of absolute place or of absolute motion). That is a result of the fact that, classical mechanics does not single out a state of absolute rest, although one can distinguish a certain class of motions, namely the class of inertial (or non-accelerated) motions. One must, therefore, carefully distinguish between Newton's own views of time and space and the "views" presupposed by his mechanics.[31]

Biographical Notes

Francis Bacon (1561–1626), English philosopher and theoretician of science. He was born in London. He studied the sciences at Trinity College, Cambridge, later studied law at Gray's Inn, served as a diplomat in Paris and then became a lawyer and began his legal career. Known as an English statesman, he was equally occupied with the theory of the sciences. He devoted his last years to his great work the *Instauratio magna* which was supposed to bring about the reform of the sciences. Bacon was not able to complete the work, writing only two of the three planned parts: *De dignitate et augmentis scientiarum* and the *Novum organum* (incomplete). The fragments of the third part were published after Bacon's death.

Isaac Newton (1642–1727), English physicist, mathematician, and theologian. He was born in Woolsthorpe in the county of Lincoln. He attended Trinity College, Cambridge. In 1665–1667, out of fear of the plague, he remained in his native Woolsthorpe. Those 2 years yielded many discoveries. Newton formulated the binomial theorem, elaborated the differential calculus, constructed the first reflective

[30] A. Koyré offered an insightful analysis of Newton's statement *hypotheses non fingo* in his *Newtonian Studies*, Chap. 3. It turns out that the statement does not have much in common with the thesis of extreme empiricism, with which it was often compared.

[31] For more on this, see M. Friedman, *Foundations of Space-Time Theories* (Princeton: Princeton University Press, 1984); R. Torretti, *Relativity and Geometry* (Oxford: Pergamon, 1983); W. Kopczyński and A. Trautman, *Spacetime and Gravitation* (New York: Wiley, 1992).

telescope, and began to lay the foundations for the theory of gravitation. Later, as a professor of mathematics, he resided in Cambridge. His views on the philosophy of nature are contained in his *Principia Mathematica Philosophiae Naturalis* (*The Mathematical Principles of Natural Philosophy*), published in 1687. In 1704, he published the *Optics*, which can be considered a perfect example of research conducted in accordance with the mathematico-empirical method.

Appendix: The Mechanistic Image of the World in Newton's *Principia*

While Cartesianism was celebrating its triumph in seventeenth century Europe, there was born on the British Isles a system which would shortly shake the very foundations of science. In 1687, Isaac Newton published his landmark *Mathematical Principles of Natural Philosophy*. The method of the natural sciences which Newton developed was in clear opposition to Descartes' system of knowledge based on "irrefutable and certain" principles of metaphysics. The *Principia* pointed the way to a *mathematico-empirical* method. The structure of the work left no doubt that we are dealing here with a work of central importance. That is evidenced not only by the scientific layer of the work but also by Newton's philosophical ideas.

The first book of the *Principia* contains *definitions* which have as their end precision with respect to the terms of which Newton would make use, and a *Scholium*, in which the author gives his own interpretation of his mechanics. It is worth taking note of the fact that the definitions of the fundamental quantities which we use in physics even today sprang originally from the pen of Newton himself.

In the second book, the reader finds *applications* of general principles to concrete cases. We have here to do with scientific analyses and experimental results that follow from the laws of nature.

It is in the third part of the *Principia*, in which the author, on the basis of general principles, constructs a *system of the world*, understood above all as a planetary system, where Newton really shows his genius. Beyond that, in this part of the work, the author, taking his own experience into consideration, presents a set of *rules of reasoning* by which those who study nature should guide themselves.

Among the rules of reasoning which Newton presents in the third part of the *Principia*, we find interesting ideas concerning the concept of *matter*. It might seem surprising that the scientist did not put them among the other definitions in the first part of the work. This placement is of course no accident, but is a sign that Newton does not consider the concept of matter to be a part of *physics*, but rather he understood it to be a part of *philosophy*. It is impossible to give any *operational* definition of matter, and one must clearly distinguish the term "*matter*" from the term "*quantity of matter*;" the latter term is equivalent to the concept of mass as used in physics, which has a precisely defined, operational meaning. We find the Newtonian definition of matter in the third of the rules of reasoning in philosophy. To be matter, *primary* (or universal) *qualities*. Those are extension, hardness, impenetrability, and mobility. To those properties, Newton also adds being subject to inertial motion and to gravitation, although with respect to the latter he has doubts as to whether it should be accepted as a universal quality of bodies. The definition of matter proposed in the *Principia* stands in explicit contrast to the conception of Descartes, for whom matter means only extension. It is easy to read traces of *atomism* into Newton's ideas about matter. He believes that primary qualities belong to the whole of a body because they first belong to its parts. One can seek in Newton roots of the so-called *mechanical atomism*, according to which matter consists of mechanical atoms which are subject to the same rules of motion as is macroscopic matter. One can see that, thanks to Newton, the concept of matter, removed from physics, becomes the foundation for mechanistic views in philosophy.

Newton was aware that his theory has *boundaries*, at which the laws of mechanics break down. One can point to three such places:

1. the initial conditions for the equations of motion—they do not come from the theory itself, but they must be accepted in order for the theory to function at all;
2. the general plan of the system of the world, in which thought and purpose appear;
3. the necessity of corrections to the system of the world as disturbances in the system increase over time.

In the face of those difficulties, it was necessary to accept some kind of element which would not only explain that which was not explained by the laws of mechanics, but would allow for the maintenance of continuity in the operation of the world machine. That element was, for Newton, *God*. Newton was not alone in this approach—putting the Creator in a place to which scientific theories do not reach became a relatively common practice among those scientists who were not content to leave "gaps" in a scientific system even in places that were beyond the reach of science. In Newton's opinion, God, first, gave the world appropriate initial conditions; second, in accordance with His own design, He created a world governed purposively; third, He "repairs" the world when accidental disturbances disrupt its order. Newton accepted the necessity of divine agency only at the boundaries of his theory, but asserted that because the effects of divine action we have the possibility of knowing God Himself.

Chapter 7
The World of Leibniz: The Best of All Possible Worlds

1 Leibniz and Descartes: A Contrast

Usually *Leibniz* (1646–1716) is regarded as a great rival of Newton. That is true, with respect to the achievements of these two thinkers in the field of mathematics (the creation of the differential and integral calculus) and certain positions in the philosophy of nature. But in the most important matters, concerning the foundations of philosophical thought, Leibniz most often attacked not Newton, but Descartes. Nothing is more foreign to Leibniz than a "geometrical mechanism" which reduces the essence of bodies to their extension and reduces all of their activity to purely mechanical contact like friction and impact. Leibniz' dislike of Descartes' style of thought has its foundation, however, in a certain similarity between the two philosophers. Both for the one and for the other, physics flows from metaphysics. Leibniz writes emphatically:

> it becomes more and more apparent that, although all the particular phenomena of nature can be explained mathematically or mechanically by those who understand them, nevertheless the general principles of corporeal nature and of mechanics itself are more metaphysical than geometrical, and belong to some indivisible forms or natures ... rather than to corporeal mass or extension.[1]

But that is the end of the similarity. The paths of Descartes and Leibniz diverge from the very outset. For Leibniz, the world is most of all, dynamics. Force (metaphysically understood) is the fundamental concept of Leibnizian mechanics and the "raw material" of his world.

The *dynamis* of Leibniz' world extends beyond that world and has its source in Leibniz' God. Here also, Descartes' view was strikingly different. The Cartesian God, just as he was not subject to the laws of mechanics was not subject to the laws of logic or of mathematics; He creates the "first principles" just as He creates the laws governing "extended matter." For Leibniz, such an assertion is almost

[1] G. W. Leibniz, *Discourse on Metaphysics*, §18, trans. Roger Ariew and Daniel Garber, in G. W. Leibniz, *Philosophical Essays* (Indianapolis: Hackett, 1989).

blasphemy. God and Logic are one. The *dynamis* of the world is identified with its logical consistency. An exposition of Leibniz' philosophy of nature should begin from the principles of logic.

2 The Logic of God and the Logic of the World

Liebniz' God cannot act illogically, because He cannot act against Himself. Therefore, it is not surprising that the structure of Leibnizian philosophy resembles an axiomatic system. Here is the starting point:

> Our reasonings are based on *two great principles: that of contradiction*, in virtue of which we judge that which involves a contradiction to be false and that which is opposed or contradictory to the false to be true.
>
> And *that of sufficient reason*, by virtue of which we consider that we can find no true or existent fact, no true assertion, without there being a sufficient reason why it is thus and not otherwise, although most of the time these reasons cannot be known to us.[2]

The logical status of the principle of contradiction (actually, it should be called the principle of non-contradiction) is not controversial. The principle of sufficient reason requires appeal to substantial, and not purely formal, argument; for it is not a logical principle. In philosophical practice, citation of "sufficient reasons" in support of a thesis only makes the thesis more probable. But not in the ontological logic of Leibniz. The logic of God tells Him always to choose *the best of all the possibilities* and precisely that is the *sufficient reason* for everything that happens, other than that which follows from the principle of non-contradiction. From this, it follows:

> There are also two kinds of *truths*, those of *reasoning* and those of *fact*. The truths of reasoning are necessary and their opposite is impossible; the truths of fact are contingent, and their opposite is possible.[3]

Theorems of logic and mathematics are rational truths. Their truth can be shown "by decomposition" or by reducing them to the principle of non-contradiction (or to the principle of identity). Truths of fact (also called by Leibniz "contingent truths") concern things spread across the universe. In relation to such truths, "decomposition into their parts" would not lead anywhere. "Because of the immense variety of things in nature and because of the division of bodies to infinity," reduction to ever-smaller fundamental elements would never end. "That is why the ultimate reason of things must be in a necessary substance," i.e., in God.[4]

In Leibniz' view, *rationalism* reached its peak. The world can be inferred from logical principles, supplemented by the principle of the better choice, and that choice itself has its ultimate justification in rational reasons:

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[2] G. W. Leibniz, *The Principles of Philosophy, or Monadology*, §§31–32.

[3] Ibid., §33.

[4] Ibid., §§36 and 38.

> God is not only the source of existences, but also of essences .... This is because God's understanding is the realm of eternal truths or that of the ideas on which they depend. Without him there would be nothing real in possibles, and not only would nothing exist, but also nothing would be possible.[5]

3 The World of Substances

The Necessary Substance, i.e., God, brings forth from its intellect everything that exists, even down to the smallest details. In the *Discourse on Metaphysics*,[6] Leibniz insightfully (but at the same time rather technically) shows, how it is that God sees in the essence of Alexander the Great:

> ... the basis and the reason for *all* the predicates which can be said truly of him, for example that he vanquished Darius and Porus; he even knows a priori (and not by experience) whether he died a natural death or whether he was poisoned, something we can know only through history.[7]

If everything is thus determined "from above," is it possible to speak about contingent truths and about non-determination at all? Leibniz' answer is as follows: God foresees the whole life of Alexander in an absolutely certain way; that foresight is based on "his free decree to do what is most perfect." In Leibniz' opinion, "every truth based on these kinds of decrees is contingent, even though it is certain." It is contingent because its denial does not lead to a contradiction; "nothing is necessary whose contrary is possible."[8]

That maximally understood logical consistency of the world establishes a unique connection between all existing substances and the Necessary Substance. All logical substances come from God and draw from Him all their being. Logic is here also ontology. By means of logical-ontological connections, every substance somehow sees (or feels) in God all other substances. Here is a classical passage from Leibniz:

> ... every substance is like a complete world and like a mirror of God or of the whole universe, which each one expresses in its own way, somewhat as the same city is variously represented depending upon the different positions from which it is viewed. Thus the universe is multiplied as many times as there are substances, and in some way the glory of God is likewise multiplied by as many entirely different representations of his work. It can even be said that each substance bears in some way the character of God's infinite wisdom and omnipotence and imitates him as much as it is capable.[9]

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[5] Ibid., §43.

[6] See Leibniz, *Discourse*, §8.

[7] Ibid.

[8] Ibid., §13.

[9] Ibid., §9. See also: G. W. Leibniz, *Monadology*, §7.

Leibniz did not write his discourses in the form of dry treatises with carefully drawn definitions; if, however, we wanted to find a passage as close as possible to a definition, our choice would have to fall on this formulation:

> Since this is so, we can say that the nature of an individual substance or of a complete being is to have a notion so complete that it is sufficient to contain and to allow us to deduce from it all the predicates of the subject to which this notion is attributed.[10]

For that is the logical understanding of substance. The constitutive feature of substance is that, from substance itself one can deduce all its properties (although the chain of deductions can be infinitely long). But God can do that, for His logic is not fettered by human limitations. A distant analogy can be seen in the concept of a mathematical progression, for example the sequence of general expressions 1/n, where *n* designates successive positive whole numbers. Knowing the general expression, one knows that the sequence contains infinitely many terms: 1, 1/2, 1/3, 1/4, . . ., without the necessity of writing them all.[11]

Dotting the "i," one should add that substances, which Leibniz calls *monads*, are a kind of "metaphysical atom;" they do not have any extension; they have a dynamic nature and they are the source of action. But this action is of a peculiar sort, completely opposed to Cartesian interactions by immediate contact. Contact between monads occurs exclusively on the basis of a chain of logico-ontological connections originating in the Necessary Substance. Those connections established from the beginning all later connections between monads. That is Leibniz' famous doctrine of *pre-established harmony*. Let us once again cite a passage from Leibniz:

> God alone . . . is the cause of this correspondence of their phenomena and makes that which is particular to one of them public to all of them; otherwise, there would be no interconnection. We could therefore say in some way and properly speaking, though not in accordance with common usage, that one particular substance never acts upon another particular substance nor is acted upon by it, if we consider that what happens to each substance is solely a consequence of its complete idea or notion, since this idea already contains all its predicates or events, and expresses the whole universe.[12]

After those explanations, the following short passage from Leibniz is very rich in content:

> Now, this interconnection or accommodation of all created things to each other, and each to all the others, brings it about that each simple substance has relations that express all the others, and consequently that each simple substance is a perpetual, living mirror of the universe.[13]

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[10] Ibid., §8.

[11] See J. Ladrière's Chap. 3 "Physique et philosophie. Leibniz," in his *Physique et Métaphysique*.

[12] Leibniz, *Discourse*, §14.

[13] Leibniz, *Monadology*, §56.

4 Teleology of the World

"The costs of a building [must be in balance with] the size and beauty one demands of it." If earthly architects follow the principle of harmony, then it pertains all the more to the Builder of the World. But Leibniz immediately remarks: "It is true that nothing costs God anything—even less than it costs a philosopher to build his imaginary world out of hypotheses." With the remark, however, that the hypothesis of God is not an imaginary world. "God only has to make decrees in order that a real world come into being." The comparison, however, is relevant: "in matters of wisdom, decrees or hypotheses take the place of expenditures to the extent that they are more independent of one another."[14]

As is already clear from what was said above, the principle of the choice of the better has a fundamental significance in the balance of possibilities executed by the Creator. That principle was the object of frequent attacks and misunderstandings. Beings, taken in isolation from others, do not necessarily realize the most perfect possibility. The perfection about which Leibniz speaks is a *relative perfection*, after taking into account all the interactions initiated by the given being with the totality of all other beings. God—in Leibniz' opinion—chooses a world "which is at the same time the simplest in hypotheses and the richest in phenomena."[15] It is necessary, however, to acknowledge that the morality of the Creator (His choice of the best) has in itself a great degree of logical calculation. Although the very decision to create that which is better rather than anything else is a free decision of God (the opposite, i.e., the creation of that which is not necessarily better, would not be a contradiction), once God undertook that decision, the rest is reduced to a purely combinatorial review of all the possibilities and the choice of the best. The morality of the Creator becomes a part of his logicality.

Leibniz' doctrine of pre-established harmony and the principle of the choice of the better leads to a *teleological* understanding of the world. The world is not a system whose operations are completely determined by efficient causes. The choice of the best of all possible "configurations of things" establishes an *end* (*telos*) for the universe and the pre-established harmony so "pre-establishes" the world, that that end is realized.

The calculus of infinitesimals (the differential and integral calculus), and more precisely, the method of determining the extremes of a function, established by Leibniz provided him the intuitive foundation for a teleological understanding of the world. Leibniz' God, in a certain sense, resolves the puzzle of the extremes—and searches for an "extremely" good world. Writing about the benefits of using the principle of teleology, Leibniz appeals directly to the work of Snell and Fermat, who discovered laws of geometrical optics by use of the method of extremes.[16] That is

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[14] All of the citations in this paragraph come from Leibniz, *Discourse*, §5.

[15] Ibid., §6.

[16] "I also believe that Snell, who first discovered the rules of refraction, would have waited a long time before discovering them if he first had to find out how light is formed. But he apparently

not the only case in which Leibniz' accomplishments in the sphere of mathematics had a great influence on his philosophical views. As many passages from his writings show, Leibniz was very taken with the idea of *continuity in nature* and ascribed to that idea great metaphysical significance (in contrast to Descartes). As in the case of Newton, this was a clear consequence of inspirations flowing directly from the "infinitesimal calculus."

5 From Metaphysical Dynamics to Physical Dynamics

I remarked above that Leibniz understood the concept of substance dynamically. But how than that be reconciled with the doctrine that substances do not interact with one another? Let us compare two passages from the *First Principles*[17]:

> . . . no created substance exerts a *metaphysical* action or influx on any other thing.

and:

> Every individual created substance exerts *physical* action and passion on all the others.

For Leibniz, that was an important distinction: metaphysically, substances do not interact with one another; each of their actions comes from God on the basis of the pre-established harmony, but thanks to that harmony, in the physical order, everything looks as though substances interact with one another. In this way, metaphysics becomes a foundation for physics. The physicist, discovering the laws governing the interaction of substances, is in reality discovering the plan of the pre-established harmony.

Leibniz constructed a net of subtle distinctions, in order to make such a metaphysical conditioning of physics evident. I consider that part of Leibniz' views less interesting: I mention it only very briefly. It is not to be ruled out that it is precisely this overdependence of physics on philosophy that barred to Leibniz the way to a correct mechanics.

Everything that was said above on the topic of substance concerns only *simple substances* (monads). We will not go into the mysteries of Leibniz' architecture of sensible bodies. We will say only that—according to Leibniz—bodies consist of many monads somehow coordinated by the central monad, which plays the role of a soul (*entelecheia*) or of a substantial form. That form—and not extension,

followed the method which the ancients used for catoptrics, which is in fact that of final causes. For, by seeking the easiest way to lead a ray of light from a given point to another point given by reflection on a given plane (assuming that this is nature's design), they discovered the equality of angles of incidence and angles of reflection . . . . That is what, I believe, Snell and Fermat after him (though without knowing anything about Snell) have most ingeniously applied this to refraction." (*Discourse*, §22.) The catoptrics (the science of reflection) mentioned in that passage as well as dioptrics (about the construction of optical equipment) were considered in Leibniz' day to be parts of optics.

[17] G. W. Leibniz, *First Principles*, trans. Roger Ariew and Daniel Garber, in G. W. Leibniz, *Philosophical Essays* (Indianapolis: Hackett, 1989), 30–34 at 33. Emphasis mine.

as for Descartes—is the essence of the body. What is more, that form—again in contradistinction to extension—has a dynamic nature, is a force—an active force, as Leibniz called it. In addition to an active force, bodies are characterized by a passive force; thanks to it, bodies are massive and impenetrable and have the ability to resist change. The passive force, therefore, calls to mind Newton's inertia.

<table>
<tr><th colspan="3">Kinds of force according to Leibniz</th></tr>
<tr><td colspan="2">Active force

(the dynamic form of a body)</td><td rowspan="2">Passive force

(which gives bodies the features of massiveness and impenetrability)</td></tr>
<tr><td>Primitive

(for isolated bodies)</td><td>Derivative

(for bodies interacting with other bodies)</td></tr>
</table>

That is not the end: Leibniz divides *active force* into *primitive and derivative forces*. A body isolated from others, regardless of any interaction with the environment, is also a seat of forces—these are primitive forces. Derived forces are the result of the interaction of a given body with other bodies. Those bodies, in a certain sense, limit the primitive force, imposing on it certain constraints which result from the fact that the body does not exist alone but is in interaction with other bodies. Physics studies derivative forces.

Leibniz did battle with Descartes also in physics, claiming that the derivative force (which Leibniz also called *vis viva*, "living" force) is not equal to the product of mass and velocity (mv), but is equal to the product of mass and the square of velocity (mv^2), We recall that in Newton's mechanics, the magnitude mv is called the momentum and half the magnitude mv^2—kinetic energy. As is well-known, both those magnitudes play an important role in mechanics, but taking either of them as a definition of force leads to inconsistencies. Let us add that Leibniz lacked clear definitions of other important concepts lying at the foundation of mechanics (e.g., Leibniz sometimes uses the concept of mass interchangeably with the concept of body) and without those, the construction of a correct mechanics was impossible.[18]

Newton created a mechanics which had a great influence on his philosophical views. For Leibniz, the influence was in the opposite direction—he sought the foundations of mechanics in metaphysics. It is possible to defend the claim that Leibniz was a better philosopher than Newton, but there is no doubt that as a physicist Newton greatly excelled Leibniz.

[18]For more on the concept of Leibniz' mechanics, see the chapter "Physique et philosophie: Leibniz," in Jean Ladrière, *Physique et Métaphysique*, 8–20.

6 The Relational Theory of Space and Time

The polemic between Leibniz and the staunch Newtonian, Samuel Clarke, is largely responsible for historians' tendency to oppose Leibniz to Newton rather than to Descartes. The exchange of letters between Leibniz and Clarke has given to philosophical literature one of its most beautiful pearls: living testimony to the uncompromising search for truth reaching the depths of the personalities of the two authors. One of the main topics of the polemics was the conception of space and time—a point on which the philosophy of nature makes contact with metaphysics.

For Leibniz, time and space cannot be absolute. All places in absolute space are equivalent and moments in absolute time do not differ at all one from another. When some event occurs at a given place and time, then given the equivalence of all places and times there is no sufficient reason why the even should occur here and now rather than at some other place and time. Such a sufficient reason can be had only by putting the event into space and time relative to other events which occur in space and time. Newton's absolute space and absolute time are replaced in Leibniz by *relative space and relative time*. Here is the classic passage from Leibniz:

> As for my own opinion, I have said more than once, that I hold space to be something merely relative, as time is; that I hold it to be an order of coexistences, as time is an order of successions.[19]

Leibniz' physical world can be imagined as a great collection of "things," in which for the purpose of these considerations, a "thing" is characterized exclusively by the position in space and time in which it is occurs; in agreement with contemporary linguistic convention, it would be better to use the term *event* than the term thing. The collection of events is "ordered" with the help of two relations: the order resulting from the relation of the "*co-existence of events*" is called *space*; and the order resulting from the "*succession of events*" is called *time*. For obvious reasons, this doctrine of Leibniz is called *the relational conception of space and time*.

When there are no events ("things"), the concept of relations ordering a collection of events becomes meaningless, and therefore—in contrast to the views of Newton—empty space and empty time are something logically contradictory, and therefore they cannot exist. Just as, according to Newton, space and time have the *status of things*, so for Leibniz they must be given the character of relations between *things*. If, according to Newton, God created the world in (absolute) time and in (absolute) space, then according to the doctrine of Leibniz one must affirm that God created the world together with time and space.

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[19] *The Leibniz-Clarke Correspondence*, ed. H. G. Alexander (Manchester: Manchester University Press, 1956), Leibniz' Third Paper, ¶4.

It is not a well-known fact, that towards the end of his life Leibniz supplemented his doctrine of time and space by creating the so-called *causal conception of time*.[20] In this conception, the relations constituting time are of a causal character. If all events were put into a chain, such that each preceding link in the chain contained the sufficient reason for the events constituting the following links, then the causal order attained in that way would coincide with the temporal order of the events. In Leibniz' opinion, we can even say that the causal relations define the arrow of time (or, the direction of time). It is also worth noting that—despite a relatively widespread view—in Leibniz' world there is not a plurality of times (which could, for example, depend on the system of reference, as in the theory of relativity), but (as in Newton) with one time, such that there is no absolute time, but only a time determined by causal relations (or more precisely, relations between sufficient reasons and their consequences).[21]

* * *

Leibniz and Newton each offered weighty arguments in support of their views; and they put forth against each other charges that were hard to sustain. Some of the theses went far beyond the possibilities of the science of their day, demarcating future directions of research.[22] Leibniz' philosophy might have appeared then to be more attractive than did Newton's views, but Newton remained in possession of an unanswerable asset: in support of his philosophical claims, he appealed to the mechanics which he had created, a mechanics in which those claims were supposed to function; Leibniz did not have such an asset, his mechanics never went beyond his initial intuitions. That circumstance turned out to be decisive: Newton's doctrine about absolute time and space became the view of the next two centuries. Only the rise of the theory of relativity led to a "return to Leibniz." There are even many voices who say that, Albert Einstein was, finally, able to create a physical theory that realized Leibniz' doctrine of time and space. Those voices are, however, based on a misunderstanding. It is true that, in Einstein's theory (in the general theory of relativity) the presence of "things" (energies, masses, momenta, etc.) modifies the structure of space and time (or space-time); that does not, however, fully realize the idea of Leibniz because in the general theory of relativity empty space-time can exist, i.e., space-time unfilled by "things," which is a completely anti-Leibnizian element of the theory.[23]

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[20] See *Initia rerum mathematicarum metaphysica*, in *Leibnizes mathematische Schriften*, ed. K. Gerhardt (Halle: Schmidt, 1849–1863), 7: 17–29.

[21] For more on this, see H. Mehlberg, *Time, Causality, and the Quantum Theory* (Dordrecht: Reidel, 1980), volume 1, 42–50.

[22] On the contemporary relevance of themes from the Leibniz-Clarke polemic, see M. Heller and A. Staruszkiewicz, "A Physicist's View on the Polemics between Leibniz and Clarke," *Organon* 11 (1975): 205–213, or, in a more popular form, M. Heller, *Początek Świata* (Cracow: Znak, 1976), 82–91.

[23] For more on this, see D. J. Raine and M. Heller, *The Science of Space-Time* (Tucson: Pachart, 1981).

Biographical Notes

Gottfried Wilhelm Leibniz (1646–1716), German philosopher, born in Leipzig. At the age of fifteen, he began to study at the university, where he studied law, mathematics, and philosophy. At seventeen, he wrote his first treatise, *De principio individui*; 3 years later, he became a doctor of law. He actively participated in political life, worked on educational, legal, and religious reforms, the latter especially in the area of interconfessional reconciliation. He was a member of the British Royal Society, the French Academy, and the Prussian Academy. In 1674, he invented the differential calculus. The variety of Leibniz' interests and his great abilities had their effect on many-sidedness of his accomplishments. From among Leibniz' many writings, the most valuable to philosophy are his *Theodicy* (one of the few works published during his lifetime), the *Principle of Individuation*, the *Discourse on Metaphysics*, the *New System of Nature*, the *New Essays on Human Understanding*, the *Principles of Nature and of Grace*, the *Monadology*, and his correspondence with Samuel Clarke.

Samuel Clarke (1675–1729), English cleric, theologian, and philosopher. He began his studies at a school in Norwich, later he studied at Caius College, Cambridge. In 1628, he became chaplain to the bishop of Norwich, John Moore, and at the same time began his scientific work. Clarke mainly published theological treatises. He was also translator of Newton's *Optics*. His polemic with Leibniz, which appeared in 1715–1716, became famous. Clarke, who wrote on the side of Newton, subjected Leibniz' system to critique.

Appendix: The Leibniz-Clarke Debate

Debates between leading scientists present a vivid image of the development of scientific thought. Near the end of last chapter, mention was made of the polemical correspondence between Leibniz and Samuel Clarke, the Anglican cleric who was not only a friend of Newton but an ardent adherent of his views. The roots of the dispute reach back to the 1660s, when both Newton and Leibniz, independently of one another, discovered the *differential calculus.* The dispute over who did this first and over whether the discoveries were in fact independent gave birth to a mutual dislike between the scientists. In addition, Leibniz was hurt by the decision of the Royal Society, which decided the dispute to his disadvantage. When, several years later, Clarke was supposed to translate Leibniz' *Theodicy* into English, its author not only objected strongly to this proposal, but, in the course of justifying his decision, launched a broad critique of Newton's views. The entire correspondence was conducted through the mediation of the Princess of Wales, Wilhelmina of Ansbach. Although the dispute was driven by personal concerns, the dispute itself was unusually valuable in the development of modern philosophical thought.

The polemical character of the writings of both authors shows perfectly the philosophical profile of Newton and Leibniz. The first appears as a *physicist-empiricist* for whom philosophy is rather the consequence of his physical system than its foundation; the second appears as a *philosopher-rationalist*, whose views about nature flow naturally from his philosophical system. It is worth taking note of the fact that the dispute between Newton and Leibniz begins at the *epistemological* level and it is possible to read it as an example of the dispute between empiricism and rationalism. The main themes of the dispute between Newton and Leibniz concerned the most important philosophical problems as well as problems concerning the structure and nature of the world. Leibniz' dream of building a model of the world by deduction from a few fundamental logical principles became a rival to Newton's experientially confirmed model.

The problem of *space* and *time* was one of the most important themes in the Leibniz-Clarke debate. As we already read in this chapter, the principle of sufficient reason was, along with the principle of contradiction, a pillar of Leibniz' system. Leibniz used that very principle to undermine the theses about the absolute character of time and space. He wrote:

> Space is something absolutely uniform; and, without the things placed in it, one point of space does not absolutely differ in any respect whatsoever from another point of space. Now from hence it follows, (supposing space to be something in itself, besides the order of bodies among themselves,) that 'tis impossible there should be a reason, why God, preserving the same situations of bodies among themselves, should have placed them in space after one certain particular manner, and not otherwise.[24]

In reply, Clarke wrote in his third letter to Leibniz:

> Undoubtedly nothing is, without a sufficient reason. . . . But in things in their own nature indifferent; mere will, without any thing external to influence it, is alone that sufficient reason. . . . And therefore no argument can be drawn from this indifferency of all places, to prove that no space is real. For different spaces are really different or distinct one from another, though they be perfectly alike.[25]

The *cosmological* and *methodological* arguments of the two authors were closely connected to *theological* questions. For the dispute also concerned both nature and the role of God in the world. As we recall from the previous chapter, Newton's God appeared at the boundaries of his theory, being a supplement and a keystone of the entire system. And it is just at this point that one of Leibniz' charges hit home. According to him, God created the best of all possible worlds, in which there is no necessity for constant corrections. A pre-established harmony, in which the divine mind is expressed, eliminates in advance all the imperfections of the world. Leibniz' accusation against Newton was that the disorder which appears in his world would be evidence of disorder in God Himself, and that would be connected with

[24] *Correspondence*, Leibniz' Third Paper, ¶5.

[25] *Correspondence*, Clarke's Third Reply, ¶2.

a recognition of an imperfection in his nature. Clarke replies to the accusation as follows:

> The *active forces*, which are in the universe, diminishing themselves so as to stand in need of new impressions; is no inconvenience, no disorder, no imperfection, in the workmanship of the universe; but is the consequence of the nature of dependent things. Which dependency of things, is not a matter that wants to be rectified.[26]

The fragments presented above are only a sample of the style in which the dispute was conducted. It is worth adding that some of its themes remained unfinished. Although the death of Leibniz broke off the direct exchange with Clarke, the dispute about whether time and space have an absolute or a relative character continues.

It is easy to think that the latter was the most important issue in the debate between Leibniz and Newton. Newton had not only his *philosophy*, but above all a *scientific theory* which could buttress his arguments. Leibniz' philosophy, which did not have a corresponding physical model in the eighteenth century, had to wait, for its physical interpretation, until the beginning of the twentieth century. Einstein's *theory of relativity* was the candidate for such an interpretation. Although Einstein did not make direct reference to Leibniz, the same idea was explicitly present in his writings. In Einstein's formulation, the structure of space-time depends on the disposition and motions of the matter found in it, in which regard it is *relative*. Einstein said that he realized that idea when, in 1917, he successfully applied the gravitational field equations of the general theory of relativity to the universe as a whole and gave a solution—according to him, a unique one—showing that dependence. It turned out, however, that Einstein's enthusiasm was premature. First, Willem de Sitter gave a solution to the field equations which presented an empty world without matter, but with a well-defined spatio-temporal structure; later it was proved that Einstein's equations, when applied to cosmology, have infinitely many solutions. Those discoveries show that matter *modifies* space-time, but it does not determine it unambiguously. That result sheds new light on the Leibniz-Clarke debate (and more broadly on the debate about the character of space-time). Einstein, thanks to his equations, showed that there exist many possibilities that can be placed between Newton's model of absolute space-time and Leibniz' concept of relative space-time.

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[26] *Correspondence*, Clarke's Third Reply, ¶13–14.

Chapter 8
Immanuel Kant: The A Priori Conditions of the Sciences

1 The Fundamental Question: How Are the Sciences Possible?

The appearance of the empirical sciences was a qualitative novelty in the intellectual arena of modern times. From that time on, philosophers of nature can be divided into two groups—those who, knowing those sciences, were entitled to engage in philosophical reflection about nature and those who, disregarding them, put themselves outside the main line of the evolution of thought. *Immanuel Kant* (1724–1804) undoubtedly belonged to the first group. What is more, not only did he engage in philosophical reflection about nature on the basis of a well-grounded and many-sided familiarity with the natural sciences (in his *precritical* period—before 1762—Kant worked mostly in the natural sciences), he was the first to understand clearly that the very existence of those sciences is a serious philosophical problem. The attempt to solve that problem gave rise to Kant's *critical* philosophy.[1]

Descartes, and to some extent also Leibniz, must be considered to belong to the period before the rise of modern physics. Newton, and to some extent also Leibniz, are philosophers belonging to the period of the birth of modern physics. Kant is a thinker for whom the existence of an exuberantly developing physics, understood as an empirical science in the modern meaning of that term, was an undisputable fact, but a fact requiring a metaphysical justification. And so: *how are the empirical sciences* (or—to use a more Kantian expression—*a mathematical natural science*) *possible*? That question assumes an earlier question: *how is mathematics* (in Kant's understanding—mainly *geometry and arithmetic*) *possible?* Kant got interested in the questions because—in his opinion—their answers shed new

[1] The ideology of the separation of philosophy from the particular sciences appeared much later; it was a product of the tendency to "dephilosophize" science resulting from the spirit of positivism. Even if one (partially) agrees with that ideology, it is necessary to require that a philosopher extending his inquiry into the field of nature have a familiarity with the natural sciences. Otherwise—as the modern history of philosophy in science teaches—such a philosopher sooner or later unconsciously (but not inculpably) intrudes into the terrain of the natural sciences, where he will wreak methodological and substantive havoc.

light on the fundamental question—*how is metaphysics possible*? And so, these questions were for Kant the *fundamental questions*, questions that give rise to a great new philosophical system.

2 Synthetic A Priori Judgments

The key to understanding the problem posed by Kant is his division of judgments (in contemporary terminology, propositions[2]). And so, according to him, judgments can be either *only explicative*, when they do not add anything to the content of our knowledge, or *also expansive*, when that knowledge is increased.[3] The first, Kant calls *analytic* judgments; the second, *synthetic*. The judgment "All bodies are extended" is, for Kant, analytic, because it does not "amplify in the least [the] concept of body" (the obvious influence of Descartes: a body is defined by its extension). However, the judgment "All bodies have weight"—"contains in its predicate something not actually thought in the universal concept of *body*;" it is therefore a synthetic judgment.[4]

The division of judgments according to Kant	
The division of judgments on the basis of their content	
Analytic (explanatory) (= not adding anything to the content of knowledge)	Synthetic (ampliative) (= adding something to the content of knowledge)

Judgments can also be divided according to their relation to experience. A judgment is a priori (in relation to experience) when the experience is unnecessary to the justification of the judgment; a judgment is a posteriori when it comes from the experience. All analytic judgments—in Kant's opinion—can be derived from the principle of non-contradiction and therefore they are always a priori: proceeding "out of pure understanding and pure reason."[5] Judgments *a posteriori* do not create any special problems: "experience is nothing but a continual synthesis of perceptions."[6] The fundamental problem is the possibility of the existence of *synthetic*

[2]There is obviously a semantic difference between the terms "judgment" and "proposition." A proposition is a certain "linguistic unit," investigated by logic; a judgment concerns rather the "content of the proposition." Kant's preference for "judgment" over "proposition" was not only the result of an eighteenth-century habit, but also corresponded to the spirit of his system. Kant was interested not so much in the *meaning of the proposition* as in the *truth* of the knowledge it contained.

[3]See Immanuel Kant, *Prolegomena to Any Future Metaphysics*, ed. Lewis White Beck (Bobbs-Merrill, 1950), §2.

[4]Ibid.

[5]Ibid., §1.

[6]Ibid., §5.

judgments a priori. Because they would be judgments a priori, they would be necessary, not permitting the possibility of error, i.e., apodictic; because at the same time they would be synthetic judgments, they would provide information about an empirically knowable reality. A science which forms judgments a priori would deserve to be called an ideal science since it would satisfy man's eternal longing for an absolutely certain knowledge of reality. Metaphysics would be knowledge of that kind.

The division of judgments according to Kant	
The division of judgments on the basis of their relation to experience	
a priori (= in advance with respect to experience)	*a posteriori* (= derived from experience)

> Were a metaphysics which could maintain its place as a science really in existence, could we say, "Here is metaphysics, learn it, and it will convince you irresistably and irrrevocably of its truth"? This question would then be useless, and there would only remain that other question (which would rather be a test of our acuteness than a proof of the existence of the thing itself): "How is the science possible, and how does reason come to attain it?"[7]

Such a metaphysics does not exist. The best evidence of that is the diversity of statements made by metaphysicians, each claiming apodictic certainty. But despite all that, the situation is not hopeless.

> though we cannot assume metaphysics to be an actual science, we can say with confidence that there is actually given certain pure a priori synthetical cognitions, pure mathematics and pure physics. For both contain propositions which are unanimously recognized, partly apodictically certain by mere reason, partly by general consent arising from experience and yet as independent of experience.[8]

In what follows, we will see, successively, how the mechanisms which form synthetic judgments a priori in "pure mathematics" and "pure natural science" operate.

3 How Is Pure Mathematics Possible? The Categories of Space and Time

First: are the propositions of mathematics really synthetic a priori? That they are a priori, there is no doubt: "They carry necessity with them, which cannot be obtained

[7] Ibid., §4.
[8] Ibid., §4 (emphasis Kant's).

from experience”[9] and they can be derived from the principle of non-contradiction. The claim that mathematical propositions are synthetic creates greater difficulty for Kant. He cites an example. The proposition “7+5=12” is not merely an analytic proposition, because

> the concept of the sum of 7 + 5 contains merely their union in a single number, without its being at all thought what the particular number is that unites them. [§2]

In order to get to the idea that the number being sought is “12,” one must “go beyond these concepts, by calling to our aid some intuition” arising, for example, from the outcome of counting the fingers on my hand. The case is similar, according to Kant, for the propositions of geometry.

> That a straight line is the shortest path between two points is a synthetical proposition. For my concept of straight contains nothing of quantity, but only a quality. [§2]

Of course there are analytic propositions in mathematics (e.g., “The whole is equal to itself,” and “The whole is greater than its part”), but they do not serve as “principles,” but only as “links in a chain of method.”

The fact that synthetic a priori propositions are the basis of mathematics is responsible for the success that mathematics has had.

We have here a great and tested body of knowledge which has an astonishing volume even now and which promises unlimited growth.

There still remains, however, the question of the conditions under which such knowledge is possible. *In what way* is it possible to have knowledge that is completely a priori and at the same time synthetic?

On what does the mechanism which recognizes synthetic judgments depend? One can see the answer to that question best in the case of propositions accepted on the basis of experience (e.g., propositions from the empirical sciences). Here we have before us a “intuitively given” object on the basis of which we create its concept for ourselves. But “empirical intuition” still works, giving us new predicates, which we relate to the object (it becomes the subject of a judgment), and in this way expand it. Finally, we formulate a synthetic judgment, in which we ascribe to the given object something which is not contained in its concept.

One must accept an analogical intuition in the case of synthetic, but a priori, propositions. That will not, however, be an *empirical intuition, but a pure intuition*. Of mathematics he said:

> some *pure intuitions* must form its basis, in which all its concepts can be exhibited or constructed *in concreto* and yet a priori. [§7]

[9] All the passages quoted in this paragraph, unless indicated otherwise, come from the *Prolegomena* §§2–14. A more systematic exposition of the problem treated here can be found in the Introduction to *The Critique of Pure Reason*. The *Prolegomena* is a summary, often simply an extract (or selection of fragments) from the *Critique of Pure Reason*. In writing this chapter, I made great use of the exposition contained in the *Prolegomena* since the question “How is mathematics and a pure natural science possible?” is the main topic of the first part of that work.

That kind of pure intuition precedes all experience. Therefore, *it is a condition of all experience*.

And once again, how is it possible? Kant's proposed solution is the essence of his system:

> Therefore in one way only can my intuition anticipate the actuality of the object, and be a cognition a priori, namely: *if my intuition contains nothing but the form of sensibility antedating in my mind all the actual impressions through which I am affected by objects.*[10]

And so, there are *forms of sensible cognition*—Kant also calls them (sensible) *categories*—which do not come from a cognized reality but which come from the structure of our cognitive apparatus. Those categories can "fill out" the impressions which are the matter of cognition; they are, therefore, the condition of the possibility of empirical cognition and at the same time they introduce to it a priori elements. "Thus it is only through the form of sensible intuition that we can intuit things a priori" [§10].

The categories of Kant			
The category of quantity	The category of quality	The category of relation	The category of modality
• Unity • Plurality • Totality	• Reality • Negation • Limitation	• Substance • Cause • Community	• Possibility • Existence • Necessity

Kant went so far as to indicate the categories on the basis of which a "pure geometry" and a "pure arithmetic" are synthetic a priori knowledge. In the case of geometry, that category is *space*, and in the case of arithmetic—*time*.

> Geometry is based upon the pure intuition of space. Arithmetic achieves its concept of number by the successive addition of units in time. [§10]

Let us cite the classical passages from Kant:

> Time is the formal a priori condition of all appearances whatsoever. Space, as the pure form of all outer intuition, is so far limited; it serves as the a priori condition only of outer appearances. But … time is an a priori condition of all appearance whatsoever. It is the immediate condition of inner appearances (of our souls), and thereby the mediate condition of outer appearances.[11]

> Space is a necessary a priori representation, which underlies all outer intuitions. We can never represent to ourselves the absence of space, though we can quite well think it as empty of objects. It must therefore be regarded as the condition of the possibility of appearances,

[10] Ibid., §9 (Emphasis Kant's.)

[11] *Critique of Pure Reason*, trans. Norman Kemp Smith (New York: St. Martin's, 1965), 77 [A34, B50].

> and not as a determination dependent upon them. It is an a priori representation, which necessarily underlies outer appearances.[12]

The traditional problems of philosophy in science connected with space and time find in Kant a solution, as it were, in passing, as Kant was working on the nature of mathematical knowledge. From that time, Kant's theory of time and space has become one of the most discussed problems in the philosophical thought about nature.

4 How Is a Pure Science of Nature Possible?

First: what does Kant understand by *a pure science of nature*? It is not just the natural sciences, because they contain both necessary propositions and contingent ones based on experience. *A pure science of nature* is only that part of the natural sciences which discovers

> in which are propounded, a priori and with all the necessity requisite to apodictical propositions, laws to which nature is subject.[13]

Nature can also be considered *materially*: when it "refers to the totality of all objects of experience" [§16]. It is necessary to note: Not the totality of objects as things in themselves—these are not accessible to any form of knowledge, but the totality of objects as *given to us in experience*. Nature can also be considered *formally* as "the way all things fall under the *system of laws*" [§16]. The objects which constitute nature are given to us in experience, but the systems of laws to which the objects are subjected can be a priori. And here is hidden the source of the possibility of a pure science of nature.

For Kant, Newton's mechanics was the model of a pure science of nature. Kant understood clearly that Newtonian mechanics is not simply an inductive science, i.e., a simple generalization of the results of an appropriate number of observations. He knew the physics of his day well enough to realize perfectly that the general principles of mechanics contain in themselves all possible particular instances (even those which we are not yet able to imagine) and not the other way around: the sum of all the possible particular instances never yields a general principle.

In addition to the elements derived directly from experience (e.g., the results of concrete measurement) Newtonian physics contained elements that are not "entirely pure" and not entirely "independent of empirical sources." Such elements include, for example: the concept of *motion* and *impenetrability* on which, he says, the empirical concept of matter is based. General principles of pure physics, on the other hand, include, for example:

[12] Ibid., 68 [A24, B38].

[13] All the passages quoted in this paragraph, unless indicated otherwise, come from the *Prolegomena* §§14–56. Here §15.

> the propositions that "Substance is permanent," that "Every event is determined by a cause according to constant laws." [§15]

What is more—and this is the key point in Kant's doctrine—a priori principles are the *necessary condition* of empirical knowledge. And so:

> A judgment of perception can never rank as experience without the law that, whenever an event is observed, it is always referred to some antecedent, which it follows according to a universal rule. [§17]

It happens thanks to the following mechanism:

> judgments of experience always require, besides the representation of the sensuous intuition, special *concepts originally begotten in the understanding*, which make possible the objective validity of the judgment of experience. [§18]

Experience is, therefore, a synthesis of a priori concepts (or principles) with sensible perceptions. Without a priori concepts, perceptions would be undecipherable; they would not tell us about anything.

That schema provided Kant with an ambitious program. A necessary science of nature (a pure science of nature) is possible, because it depends on a priori "concepts of the intellect." And therefore, a pure science of nature can be deduced not from experience but from a priori concepts. So, it is necessary to do that:

> [I mean to ask] how the conditions a priori of the possibility of experience are at the same time the sources from which all universal laws of nature must be derived. [§17]

Despite first impressions, that is not a difficult program once one accepts Kant's previous ideas. One should not search for universal laws of nature anywhere else than among the a priori conditions of experience themselves: "the principles of possible experience are then at the same time universal laws of nature" [§23].

Later, Kant tries to reconstruct in detail the set of all a priori conditions of experience; he even gives, as he says, a complete table of a priori judgments which precisely define the "principles of the possibility of experience."[14]

A detailed analysis of these matters we leave to the historian of philosophy.

5 The Boundaries of Philosophy

In the *Critique of Judgment*,[15] Kant once again returned to the problem of a priori judgments about nature. As we already know, a priori judgments are the necessary condition of the formulation in experience of that which is particular. And so: "Judgement in general is the faculty of thinking the particular as contained under the universal." When judgment precedes perception, and perception is decipherable only in its light, we have a situation just like the one in the pure science of nature.

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[14] See ibid., §28ff.

[15] See *The Critique of Judgment*, trans. James Creed Meredith (Oxford: Clarendon Press, 1952). All the passages in this paragraph are from Sect. 4 of the Introduction.

Kant calls this kind of judgment *determinant*. The opposite situation can, however, arise, when what is given is what is particular and "the universal has to be found for it;" Kant calls such judgments *reflective*.

In order to understand that distinction, we once again give the words of the philosopher himself:

> The reflective judgement which is compelled to ascend from the particular in nature to the universal stands, therefore, in need of a principle. This principle it cannot borrow from experience, because what it has to do is to establish just the unity of all empirical principles under higher, though likewise empirical, principles, and thence the possibility of the systematic subordination of higher and lower.

Therefore, reflective judgments are also a priori in relation to experience, but they are not so much conditions of experience as they are organizing principles, giving unity to everything which was not sufficiently determined by determinant a priori judgments. In Kant's opinion, the *principle of the teleology* of nature is a reflective judgment of that kind.

It is no coincidence that these analyses are found in the *Critique of Judgment*, a work dedicated to Königsberg philosopher's aesthetics. Physics does not include everything that can be said about the world. The boundaries of physics (and in general of the science of nature) are determined by the limitations of determinant judgments. But in addition to determinant judgments, there are also reflective judgments, and it is the latter that make it possible for us meaningfully to predicate of the world that about which one would have to remain silent if all judgments were determinant judgments. The world of Newton's physics is a completely deterministic one and it is not determined by experience, but by the a priori principle of causality, which conditions experience. But there is also a sphere of freedom, free striving for a goal. It is also a priori insofar as it does not condition possibilities, but unify diversity.[16]

That is a skillful evasion, thanks to which Kant did not allow himself to be limited by the narrow mechanism of his day.

6 A Critique of the Kantian Critique

Kant's most valuable achievement is the questions that he put: How is mathematics possible? How are the empirical sciences possible? What are the conditions (presuppositions) which make experience possible? From the time of Kant, every responsible philosophy of nature and philosophy of science must reckon with these questions. However, the answers given by Kant can no longer be maintained. They had to be set aside in light of further methodological reflection on the sciences: today, no one thinks that either mathematics or the natural sciences possess apodictic knowledge in the sense understood by Kant.

[16] Cf. J. Ladrière's chapter "Physique et philosophie," in his *Physique et Métaphysique*.

Mathematical theorems are necessary, but with a relative necessity, i.e., they are (given rules of deduction) necessary consequences of axioms, but both the axioms and the rules of deduction are accepted on the basis of convention, i.e., in principle arbitrarily.

Discussions of the methodological status of the empirical sciences continue and are as far from resolution as they were in Kant's time, but there is a general agreement that there are no necessary elements in the sciences. Hypothetical deductivism (Popper), the incommensurability of paradigms before and after scientific revolutions (Kuhn), the state of constant revolution (Popper again), and the principle that "anything goes" (Feyerabend) completely destroyed the Kantian claim about the apodictic.

Of course, Kant's questions, after their necessary modification, remain current and have become even more urgent: how, given their non-apodictic character, are the successes of the empirical sciences possible? Why can mathematics, despite the conventional character of its axioms, be applied so successfully to the description of the world of experience? Or, more concisely, why is nature mathematical? What features should be ascribed to the world and to the human mind, in order that everything would be understood?

But there is no return to the answers offered by Kant. They were ruthlessly eliminated by the development of the sciences themselves. One sees that most clearly in the case of geometry. The theorems of Euclid's geometry are—in Kant's opinion—necessary a priori, because they do not come from experience, but are the result of the structure of our cognitive equipment being as it is, and not otherwise. We can document that by citing two passages:

> geometrical propositions, that, for instance, in a triangle two sides together are greater than the third, can never be derived from the general concepts of line and triangle, but only from intuition, and this indeed a priori, with apodeictic certainty.[17]

The appearance of geometries different from Euclid's overturned views like that one. As is known, in the so-called Minkowski geometry, the sum of two sides of a triangle is shorter than the length of the third side.[18]

> all external objects of our world of sense must necessarily coincide in the most rigorous way with the propositions of geometry; because sensibility, by means of its form of external intuition, namely, by space, with which the geometer is occupied, makes those objects possible as mere appearances.[19]

Kant here presents a view which he takes to be completely certain, namely, he thinks that the "external world" must be precisely described with the help of the theorems of the only possible geometry—Euclidean geometry, of course, since no other was then known. It is not enough that we now know of an infinitely

[17] *Critique of Pure Reason*, 69 [A25/B39].

[18] See, for example, R. K. Sachs and H. Wu, *General Relativity for Mathematicians* (New York: Springer, 1977), 42–43.

[19] *Prolegomena*, §13, Remark I.

many geometries, but—as Einstein's theory of relativity teaches—it is most probable that it is precisely one of those non-Euclidean geometries that correctly (i.e., with good accuracy) describes the world. That latter proposition is basically an empirical proposition, i.e., a proposition which can be challenged by the results of a confrontation with experience.

There were various attempts, undertaken by neo-Kantians, to defend Kant's philosophy against its fatal conflict with the post-Kantian history of geometry. Reinterpretations of Kant's philosophy that would have extricated it from this conflict would probably have been possible,[20] but that does not alter the fact that the development of geometry ran contrary to the guidelines laid down by Kant.

Are there not, in the empirical sciences, elements a priori with respect to experience? Of course there are. That was shown, for example, in the fiasco of the neopositivist program of translating all of physics into directly empirical propositions (so-called elementary propositions). Theories of contemporary physics are much richer than the set of empirical data. That essential "surplus" comes, however, from the freely (although in a way consistent with experience) chosen mathematical structures which model a given sphere of reality and not from the a priori conditions which come from the constitution of our cognitive equipment.

Another thing that we encounter here is the surprising new problem: mathematical structures are chosen, in principle, arbitrarily, but it very often later turns out that they explain an extraordinarily wide range of phenomena, generally much broader than that, for which they were initially invoked. It is important to be aware that all of contemporary theoretical physics can be reduced in essence to several equations. But those equations are not distinguished by any a priori necessity. If the predictions which result from them did not agree so well with the results of experiments, then there would be nothing to distinguish them from the infinitely many other possible mathematical equations.

Does that all mean that there is something innate in our cognition, something preceding experience? Current research, for example, in the field of linguistics, indicates that such forms probably exist. But they do not have to be Kantian a priori forms and probably they are not. Research from the field of evolutionary theory leads to the conclusion that man possesses many structures which determine his behavior (including cognitive behavior) coded into his genes. Those structures are a priori with respect to any acquisition of knowledge by the individual, but they are not a priori with respect to the acquisition of knowledge by the species. They were obtained by means of the ordinary mechanisms of biological

[20]It is possible, for example, to say that for Kant's doctrine, what is essential is only that *the space of our experience* has to be *locally* Euclidean. That seems, however, to be in contradiction with the original principles of Kant's philosophy. According to that philosopher, the laws of geometry generally (and therefore of geometry understood globally, and not only locally) are Euclidean by a priori necessity. Moreover, this type of evasion does not avert other charges against Kant's philosophy.

evolution.[21] Those observations form the starting point for several different versions of neo-Kantianism.

Biographical Notes

Immanuel Kant (1724–1804), Born in Königsberg, where he spent his entire life. He began philosophy and theology at the university in Königsberg, where he spent his entire academic career. In 1770, he became professor of metaphysics and logic. His main work *The Critique of Pure Reason* brought him much fame in academic circles; nevertheless, Kant, because Königsberg was not a major academic institution, he did not participate directly in the academic life of eighteenth century Europe. Kant's philosophical development is divided into two phases—the pre-critical and the critical. Only the latter earned him the reputation of being one of the greatest philosophers in history. He wrote three well-known critiques: *The Critique of Pure Reason*, containing his epistemology; *The Critique of Practical Reason*, concerning ethics; and *The Critique of Judgment*, about esthetics and the philosophy of the organic world. Among the other works of his critical period, it is worth mentioning his *Prolegomena to Any Future Metaphysic*, *The Foundations of the Metaphysics of Morals*, and successively, lectures in the philosophy of history (*Ideas for a Universal History from a Cosmopolitan Point of View*), the philosophy of nature (*Metaphysical Foundations of Natural Science*), and the philosophy of religion (*Religion within the Limits of Reason Alone*).

Appendix: The Kant–Laplace Cosmological Hypothesis

Inspired by Newtonian mechanics, *Immanuel Kant* developed an original hypothesis, which was supposed to explain the origin of the solar system. Kant's idea, even though it was imprecise and lacked a solid scientific foundation, is worthy of note if only because of its later development in an hypothesis proposed (independently of Kant) by Laplace. In 1755, Kant proposed an hypothesis explaining the origin of planetary systems as well as various stellar systems (which he called "systematic constitutions"). He said that a planetary system arose from a rotating cloud of gas. Inside the whirling cloud, stars, planets, and their moons were formed from the condensation of matter. The main problem with Kant's theory was the lack of scientific foundation. Further, the theory was not free of imprecision. At the beginning of his cosmogonic speculations, the philosopher of Königsberg accepted some tacit premises, such as the existence of a whirling gas cloud and the assumption that in a whirling gas cloud there really would be a condensation of the dispersed matter.

More than half a century later, the French physicist and mathematician *Pierre Simon de Laplace* formulated a cosmogonic hypothesis which can be seen as the

[21] Many interesting observations on the connection between the theory of evolution and traditional philosophical problems can be found in Jacob Bronowski, *The Origins of Knowledge and the Imagination* (New Haven: Yale University Press, 1978).

development of Kant's theory. Sometimes, the hypothesis that the planetary system evolved from a gaseous cloud is even called the *Kant–Laplace hypothesis.* It is worth emphasizing that the identification of their views is not entirely correct. Laplace gave up the universal character of his idea; he limited himself to the description of planetary systems and his theory, in contrast to Kant's speculations, does deserve to be called scientific.

Here is what *Laplace's cosmogonic hypothesis* says. At the beginning there was a whirling cloud of gas. When the internal temperature of the cloud began to fall, there was a thickening of the matter and the cloud began to whirl much faster. The gas cloud gradually took the form of a whirling disk. The part of the matter located at the edge of the disk broke away from the original formation and created a ring from which the planets and moons formed. From the matter which remained, the sun was formed. Laplace's hypothesis was the first to explain the origin of the planetary system without appealing to supernatural forces. Nevertheless, the acceptance of this theory was combined with the acceptance of the theory's weak points. First, it was objected, a rings of gas that could break off from the whirling disk would also be able to continue their escape into space. In that case, they would not contain enough matter for condensation and the emergence of celestial bodies—planets, and moons. Second, if the sun had in fact arisen as a result of the condensation of a whirling cloud, its motion around its axis would be much faster than is observed. Third, as is known today, some moons rotate in a direction opposite to others and it is difficult to accept that they all arose from a ring of gas that is rotating in the same direction. The difficulties mentioned above did not, however, determine the fate of Laplace's hypothesis, which was still accepted by many astronomers the nineteenth century.

Chapter 9
The Romantic Philosophy of Nature

1 Introduction: From Mysticism to Idealism

Kant's system can be regarded as a philosophical sanction for mechanism. Asking how a philosophical science of nature is possible, Kant had classical physics in mind (implicitly judging that any other physics is impossible), and Kant's whole subtle theory of perceptual knowledge was created chiefly in order to justify the claim that Newtonian absolutes—time and space—are necessary a priori. But on the other hand, at the very moment when the mechanical philosophy was being designed, elements facilitating opposition were grafted onto it. The designer of mechanism was Descartes (the designer because he clearly formulated the program of that philosophy, although he did not himself succeed in creating a correct mechanics) and it was he who introduced a fundamental distinction: mechanics is supposed to study extended matter; philosophy, unextended consciousness. Retreat to the analysis of consciousness, the philosophy of the subject, would in the future become an alternative for all those who were not satisfied, for whatever reasons, with the philosophical thought arising out of classical physics.

The philosophy of the subject had its precursors much earlier. I have in mind the current of mysticism which not only flowed rapidly through Europe over the course of the Middle Ages and Renaissance, but had a strong effect on its intellectual climate. Alexandre Koyré, studying the writings of the sixteenth century German mystics (Sebastian Franck, Valentin Weigel, Kaspar Schwenckfeld, and especially Jakob Boehme), the successors of a tradition reaching back to Meister Eckhart, came to the conclusion that their mystical doctrine was the first attempt to neutralize the effects of the Copernican Revolution and to return to man his "cosmic dignity," which had been lost with the removal of the earth from its once privileged position in the universe,[1] Koyré convincingly shows that later German idealism is a direct successor of German mysticism. Both the fundamental themes of idealism and its ways of treating them are present in the mystics. Many years of research on Hegel, Schelling, Fichte, Schleiermacher and other representatives of German

[1] See Gérard Jorland, *La science dans la philosophie: les recherches épistémologiques d'Alexandre Koyré* (Paris: Gallimard, 1981), Chap. 5.

idealism led Koyré to the formulation of the thesis that "the mystical tradition was rethought in the context of traditions associated with Kantianism."[2] The subject remains the same: "the reconquest for man of that central place in the universe which had been assigned to him by mystical theology, but which was lost to him in the Copernican revolution."[3] German Romantic idealism is a desacralized form of German mysticism.

The Romantic philosophy of nature was undoubtedly a reaction against the absolute domination of the mechanistic philosophy. That reaction sometimes took the form of a poetic protest, proclaiming a return to feeling, and not seldom to irrationalism; at other times, it took the form of philosophical discourse, i.e., both an attempt to rationalize feelings and irrationalism. Alfred North Whitehead, in the fifth chapter of his *Science and the Modern World*,[4] insightfully and beautifully (and not unpoetically) describes the poetic reaction to the mechanistic philosophy and its horror of the fact that—as the English poet Alfred Lord Tennyson expressed it—"the stars blindly run." The philosophical reaction, in the form of various Romantic philosophies of nature, will be the subject of this chapter. The terms "Romantic" and "idealistic" will be used almost interchangeably because—on the one hand—the Romanticism of the end of the eighteenth and the beginning of the nineteenth centuries came from idealistic philosophy and—on the other hand—philosophical idealism not only sought means of expression in Romantic literature, but was nourished by inspirations that flowed from it.

I decided to discuss the Romantic philosophy of nature in a book devoted to the main trends and problems of philosophy in science not because I think that Romanticism had made a significant contribution to our understanding of the world, but because it represents a style of thought which is a strong temptation for all those minds which would like to replace the difficult work of acquiring knowledge which is proposed by the natural sciences with "experience" and "feelings about things," and to use only such knowledge in the course of philosophical reflection.

This chapter should be treated as a sampling of the intellectual trend called Romantic philosophy of nature. It is in no way a complete presentation of that intellectual trend; I would like to present the views of the Romantics only to the extent necessary to justify my evaluation of their work.

2 The Mysticism of Being

The essence of mysticism is the experience of transcendence. That experience is usually connected with experience of the Absolute, adherence to it, sometimes even personal identification with it. Mystical experience is usually strongly dependent on the mystic's picture of the world and on the tradition to which the mystic belongs.

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[2] Ibid., 175.

[3] Ibid.

[4] A. N. Whitehead, *Science and the Modern World* (New York: Macmillan, 1925).

German mysticism was predominantly a mysticism of being, French mysticism—a mysticism of infinity, and Spanish mysticism—a mysticism of the soul. But—as Koyré emphasized—it is not the spirit of a nation which expresses itself in experience of mysticism, but to some extent on the contrary—it is the spirit of the nation which is shaped by the writings and language of its mystics. And so, for example, Meister Eckhart cannot be explained by reference to the spirit of the German nation, but the spirit of the German nation by reference to Eckhart.

> It is not the spirit of the German language that speaks to us through Eckhart, but rather the spirit and the thought of Eckhart that speaks to us—again and always—in the German philosophical language.[5]

Jakob Boehme (1575–1624) accepted Copernicus' system. The fact that man does not occupy the central position shows that God did not create the world for man. From that comes a feeling of loneliness. That feeling did not, however, lead Boehme to a contemplation of infinity, but, in the spirit of Meister Eckhart and the German Reformers, to a contemplation of nature. There is a precise connection between the microworld—man—and the macroworld—the Cosmos; it is enough to know oneself in order to know the universe. Or, as another mystic of that period, Sebastian Weigel, said, God is "the Being of being, the Essence of essence, and the Nature of nature," is Divine Nothingness, which exists only when it is expressed in creation. As we can see, "mystical action" occurs only in connection with nature. But nature is here understood in the spirit of the magical vitalism of Paracelsus: the whole is animated, is found in constant flux, combination, and division, and is gifted with the power of giving birth—that most beautiful manifestation of vital power which is the essence of nature.

The mystic instinctively searches for an all-explaining principle. That principle can contain in itself nothing which exists in the world because it has to explain everything which exists in the world. On the other hand, the principle which is sought has to contain in itself everything which exists in the world because it would not be able to explain anything that it did not contain. And therefore the ultimate explanation must reduce itself to contradiction. It must contain in itself "everything" and "nothing," the "internal" and the "external," "being" and "non-being," it must "descend to our knowledge" and "go beyond it." Jakob Boehme, directly formulated a "law of contradiction." The law has a three-stage structure. The knowing Absolute is like an eye looking into a mirror; here we have: the eye (statement)—its reflection (contradiction)—the process of vision, which is a kind of reconciliation of this conflict. In the terse formulation of Boehme—*In Ja und Nicht bestehen alle Dinge* ("All things are contained in Yes and No.")—we find more than just an adumbration of Hegel's dialectic. In Boehme's opinion, the principle of contradiction also acts in history: freedom and necessity, good and evil, the work of creation and the work of redemption, are a consequence of a structure of time based on the principle of contradiction.

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[5]Quoted in G. Jorland, op. cit., 177.

3 Fichte: The Romantic Theory of Science

The Romantic philosophy of nature is not understandable without frequent reference to Kant. For Kant, nature was "only the content of the forms and categories of mind,"[6] but Kant set certain limits to knowledge: things in themselves are inaccessible to knowledge. Kant, however, overlooked the fact that there exists one "thing in itself" which is directly accessible to the knowing subject. It is the subject itself, i.e., the Ego. That discovery was made by *Johann Gottlieb Fichte* (1762–1814) and it became for him a foundation for his own view of the world. Fichte considered himself to be a true successor of Kant's thought, but in fact he had turned Kant's perspective completely around: what for Kant had an epistemological character became for Fichte metaphysics.

Fichte viewed the world in the light of his "discovery." It is precisely the Ego that is the first principle of the world. Kant says that the form of objects comes from the knowing subject; Fichte maintained that even the content of objects (the objects themselves) is the work of the Ego. Although Fichte is not the chief Romantic philosopher of nature (Schelling deserves that title), he created something that can be called a Romantic philosophy of science. In his *Concerning the Concept of the Wissenschaftslehre* (1794) one can find the fundamental concepts characteristic of the Romantic relation to the world and our knowledge of it. Among the fundamental concepts of that type, one can name: *unity, totality, and organism*. These three concepts are closely connected to one another in content. The Romantics always strongly felt the postulate of the unity of science and the necessity of a comprehensive account of the process of knowledge. Knowledge should be an organic system. Particular statements attain scientific status only when they are parts of the "organism."

The organic coherence of a particular science can be assured only when it contains one *fundamental proposition* (*Grundsatz*). Every science must have such a proposition, to some extent by definition, otherwise it would not be a coherent organism and therefore would not be a science. Despite expectations, however, that does not presage any logical analysis of the sciences. Fichte contents himself with metaphors: a fundmental proposition is a solid foundation on which the walls and roof of a science are raised. From the fundamental proposition of a given science, its "internal contents" can be deduced.

Just as for the particular sciences, so it is for the system of all sciences. The "internal content" of the sciences must flow from some kind of *fundamental science*. It is the "science of science in general;" its task is to reduce everything to unity. That science Fichte calls philosophy (or also epistemology, *Wissenschaftslehre*). Of course philosophy also has to have its fundamental proposition, but because that proposition cannot be deduced from anything else, it has to be certain "with respect to itself."

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[6] Bolesław Andrzejewski, *Przyroda i język: Filozofia wczesnego romantyzmu w Niemczech* (Warsaw: Państwowe Wydawnictwo Naukowe, 1989), 14.

> All sciences—we are citing Fichte here—are included in epistemology [*Wissenschaftslehre*] not only with respect to their fundamental proposition, but also with respect to its derivative propositions; and there is no particular science, but only parts of one and the same epistemology.[7]

4 Schelling's Speculative Physics

As I already mentioned, *Friedrich Wilhelm Joseph von Schelling* (1775–1854) is considered the most important Romantic philosopher of nature. He relatively quickly freed himself from the influence of Fichte's thought and he began to develop his own conception of the world. With time, he turned more towards esthetics, ethics, and even theosophy. I will limit myself here to a short presentation of his speculations concerning the philosophy of nature.

Consistent with the spirit of idealist-Romantic philosophy, Schelling was convinced that it is possible to obtain valuable information about nature by purely speculative investigations, in a way completely independent of the empirical sciences. What is more, information obtained in that way is more significant than empirical data, for such investigations provide access to the "inside of nature," and they grasp the very living process of becoming. For Fichte, the Ego was the only "being in itself" that is accessible (and it is accessible only from inside), while Schelling maintained that we have contact with all nature "from the inside."

Schelling supplemented the German idealists' tendency to draw inspiration from Kant with a dependence on Spinoza. Schelling's thought played itself out between Kant and Spinoza. Already in his early work, "Philosophical Letters on Dogmatism and Criticism" (1795–1796),[8] Schelling defined his position in relation to those two thinkers. Criticism, of course, is the Kantian view (and also the modification of that view by Fichte); its essence is the reduction of object to subject. That view, despite its undoubted services (basically, emphasizing the role of the knowing subject) overlooks the fact that "our consciousness actually seems more to proceed from nature than nature from consciousness."[9] Schelling considers Spinoza to be the most important representative of dogmatism. Spinoza's idea of "solv[ing] the problem by absorbing the subject—the finite ego which I am—into an infinite object,"[10] strongly appealed to Schelling. But that view is not able to explain the finitude of both nature and consciousness. Therefore neither "criticism" nor "dogmatism" solved the problem.

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[7] Quoted in Andrzejewski, *Przyroda i język*, 25. There one can also find a fuller discussion of the views of Fichte, see pp. 24–38.

[8] Published in translation in F. Marti, *The Unconditional in Human Knowledge* (Lewisburg: Bucknell University Press, 1980).

[9] Étienne Gilson, Thomas Langan and Armand A. Maurer, *Recent Philosophy: Hegel to the Present* (New York: Random House, 1966), 18.

[10] Ibid.

Schelling formulated his position in *Ideas for a Philosophy of Nature* (1797). It is basically an identification of subject and object. In the introduction to the *Ideas*, Schelling wrote:

> Nature should be Mind made visible, Mind is the invisible Nature. Here then, in the absolute identity of Mind *in us* and Nature *outside us*, the problem of the possibility of a Nature external to us must be resolved.[11]

It is just because of this identity that we have direct access to the inside of nature, as a result of which a philosophical knowledge of nature, different from empirical knowledge, becomes possible.

Because the Absolute manifests itself in nature and knowledge, philosophy should consist of two organically interconnected divisions: a *philosophy of nature* coming from an analysis of the world and a *transcendental philosophy* coming from the analysis of knowledge. Schelling also calls his philosophy of nature *speculative physics*. The difference between a speculative physics and an empirical one can be reduced to the fact that the first seeks the proto-causes of the first motion, i.e., the becoming of nature, while the second limits itself to research into the second-rank causes of derivative motions.[12]

In Schelling's speculative physics, one finds the concepts characteristic of Romanticism. And so nature creates a *universum*. The ultimate knowledge which experience gives is that the *universum* exists. What is more, the *universum* defines the limits of experience. Matter and Spirit are a unity, thanks to which *organisms* emerge. The *theory of organization*, i.e., of the emergence of organisms, is a theory typical of Schelling and his Romantic followers. But one cannot see in it the embryo of the future theory of evolution since, according to Schelling's conception, life is not the product of matter, but the other way around—matter is the product of life; organism is not a property of individual manifestations of nature, but the other way around—individual phenomena are manifestations of a general organism.

5 A Philosophical Science of Nature

The term *philosophical science of nature* (*philosophische Naturwissenschaft*) was adopted to characterize the views of those thinkers who continued the tradition begun by Schelling. Representatives of that tradition include: *Henrich Steffens* (1773–1845), *Johann Wilhelm Ritter* (1776–1810), and *Franz von Baader* (1765–1841). Those thinkers are different from Schelling in that they generally

[11] F. W. J. von Schelling, *Ideas for a Philosophy of Nature*, trans. Errol E. Harris and Peter Heath (Cambridge: Cambridge University Press, 1988), 42.

[12] Schelling dedicated to a summary of that problem his work, *Einleitung zu einem Entwurf eines Systems der Naturphilosophie: oder Über den Begriff der speculativen Physik und die innere Organisation eines Systems dieser Wissenschaft* (Leipzig: Gabler, 1799). That long title—*Introduction to a Plan of a System of the Philosophy of Nature, or On the Concept of Speculative Physics and the Inner Organization of the System of this Science*—speaks for itself.

began their speculation from considerations connected to experience (they knew the empirical sciences and often practiced them), although they shared with Schelling a view about the existence of a *universum* which had a distinctly pantheistic character. Steffens wrote:

> I will proceed, as I always have, from the lowest level of experience, a position which I have in common with the physicists. . . . I hope that the way of reduction which I am following will contribute not little to the foundation and confirmation of the way of deduction which is followed by Schelling.[13]

The practitioners of the philosophical science of nature strongly emphasized the idea of the role of language in the knowledge of the *universum*, but they often understood the term language broadly. According to Steffens, language penetrates the whole *universum*, and one must identify it with the highest organization of the world. Ethnic languages are only a part of the all-embracing language of nature. (Steffens maintains that, among languages, the German language fulfills that function best!) Ritter emphasizes the role of the primordial, unverbalized language of humanity, for words make contact with the essence of the *universum* more difficult. Language without words takes the form of a "music of the universe."

> Sound and life are here one. . . . This music can be heard, to be sure, as harmony only in the sun. For the sun, the whole planetary system is one musical instrument.[14]

In Baader's opinion, external phenomena are only "symbols;" in order to make the transition from phenomena to "the depths of internal life," it is necessary to go beyond the symbols, that means "to see" and "to do." Without that activity, everything around us is dead.

These short remarks already allow us to see that the references to the empirical sciences by the practitioners of the philosophical science of nature were superficial and did not protect them from much naïveté. Here are a few more examples in support of that conclusion.

The practitioners of the philosophical science of nature were impressed by the oppositions occurring in nature and wanted to see in them a certain polarity of the *universum*, a reflection of the polarization into subject and object, Spirit and Matter. Steffens thought he could see this manifestation of general polarity in magnetism:

> Magnetism, differentiated in itself, is after all a unity of oppositions and is "the expression of a duality carried from one product to another in the original identity of nature." Magnetism is a property of all of nature, is "pure length" and is a line which is "the axis of the creation of the world." Life, as Steffens asserts, appears in a place as far removed as possible from magnetic axes, i.e., on the equator. That is where the "divine fire" was lit, where the "spirit of earth" was born.[15]

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[13] For a fuller discussion of the topic of romantic philosophy of science, see Andrzejewski, *Przyroda i język*, 59–72. All quotations in this paragraph come from there.

[14] Johann Wilhelm Ritter, *Fragmente aus dem Nachlasse eines jungen Physikers* (Heidelberg: Mohr and Zimmer, 1810), I: 225–226.

[15] The entire passage comes from Andrzejewski (p. 60); quotations within the quotation are from of Steffens, *Schriften: Alt und neu* (Breslau: Max, 1821), I: 51ff.

Another manifestation of the "unity of opposites," according to von Baader is heaviness. On this topic, he writes:

> we must treat heaviness as an immediate expression of the individual which dwells in all bodies that are separate or capable of moving for their own sakes, which individualizes itself in each such body, and which continuously places them all, sustains them and systematically orders them as an a priori principle.[16]

He remarks with equal insight that the unity of contradictions can also be seen in mechanics: when one arm of a lever goes up, the other one must go down!

Let us cite Ritter once again:

> The sun has had as many human or organic epochs as there are planets that originated from it. Thus entire human races are nothing other than individual planets, and individual planets, moons, etc., nothing more than entire human races. In that way, the solar system becomes organic to its outermost reaches, and from there to its innermost depths.[17]

6 The Debate About Hegel

Despite his rather explicitly sketched program, Schelling did not develop a complete philosophical system. Nor did the practitioners of philosophical science of nature do so. That task fell to Hegel. *George Wilhelm Friedrich Hegel* (1770–1831) is a controversial figure. Many count him among the greatest thinkers of European philosophy, but Karl Popper, for example, sees him as a charlatan.

> If Hegel's philosophy attracted a whole host of disciples, that was not because of the personal charm of its creator. He was an abrupt, cold, and phlegmatic person; even in his youth he had the character of an old man. Nor were disciples attracted by the quality of his lectures: he was a terrible speaker. Nor were his writings attractive; in their style and their terminology, they connected unclarity with pedantry. What did attract disciples, however, was the content of his doctrine, the great project incorporating all philosophical problems into a system and solving them in accordance with a single principle.[18]

Hegel's system was oriented on history, and not on a philosophy of nature, but because reality, seen historically, embraces nature as well, Hegel did not avoid drawing from his system even conclusions concerning the sphere of the empirical sciences. It is not my intention to give a full exposition of the philosophy of Hegel, but only to draw attention to the fact that in his system Romantic-idealist thought reaches its peak. I content myself with making a few textbook remarks about the foundations of Hegel's system.[19]

For Hegel—like Fichte—was a consistent idealist: things do not exist independently of thought and it is in thought that one must seek the origin of being. Since

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[16] Franz von Baader, *Sämtliche Werke* (Leipzig: Bethmann, 1851–1860), III: 257.

[17] Ritter, *Fragmente*, II: 137–138.

[18] Władysław Tatarkiewicz, *Historia filozofii* (Warszawa: Czytelnik, 1949), 2: 293–294.

[19] For more on the philosophy of Hegel, see for example Étienne Gilson, *Recent Philosophy*, 23–44.

being cannot be separated from thought, it has a logical nature. But Hegel grew out of the Romantic tradition and identified Being with the Absolute. Absolute Being is characterized by generality, unity, and mutability. That which is individual can be only a secondary manifestation of Being. Things are understood only in connection with the totality. And that totality, i.e., the Absolute, is subject to constant evolution. Because, however, the Absolute has a logical nature, its evolution is governed by the laws of logic. But the logic which Hegel proposes does not have much in common with the logic of Aristotle. Its fundamental law is the principle of the dialectic: to each proposition (*thesis*) corresponds its contradiction (*antithesis*); the tension existing between them leads to a compromise (*synthesis*). Over time, the synthesis becomes a new thesis and the cycle is repeated.

> For no statement is completely true. Truth and falsity are joined to one another, the are not absolute opposites. Truth is found both in a statement and in its contradiction, and so, in a statement which is contradictory to it. Thought need not, and even cannot, avoid contradictions, and cannot do without them. They lead through a dialectic process to the full truth.[20]

For Hegel understood all of reality evolutionarily; the process of the mutability of the Absolute is the essence of that evolution, dialectical contradiction is its mover, and the triadic schema of development is the basis of its script. *Idea* (thesis) is, for Hegel, the first form of being, *nature* (antithesis)—its opposite, and *spirit*—the synthesis of the two. To this triad correspond the three fundamental parts of Hegel's philosophy: *logic*, *the philosophy of nature*, and *the philosophy of spirit*.

The Place of the Philosophy of Nature
in Hegel's Triad

Philosophy of Spirit
↑
SPIRIT
(synthesis)

↗ ↖

IDEA (thesis) ↔ NATURE (antithesis)

↓ ↓

logic | the philosophy of nature

Hegel considered the greatest "successes" to be the application of his central idea to the philosophy of history, the state, law, and morality, but here also he met with sharp criticism. Popper accused Hegel of historicism, i.e., of defending a view

[20] Władysław Tatarkiewicz, *Historia filozofii*, 2: 296.

according to which laws govern history independent of the law of man. In Popper's opinion, that is a philosophical form of the enslavement of man, since it deprives him of the initiative of a free, and therefore responsible, shaping of his own history.[21] Popper goes on to accuse Hegel of being the first man in the history of philosophy to be the paid ideologue of a regime (the Prussian state).

It is not my intention here either to offer an evaluation of Hegelian philosophy of history, of the state, and of law, or a determination of the well-foundedness of all the accusations made by Popper. It is, however, an indubitable fact, that the "method of Hegel," applied to problems raised by the empirical sciences (which Hegel himself in no way avoided) led to reckless and sometimes even grotesque results. In the opinion of the Polish translator of Hegel's *Encyclopedia of Philosophical Sciences*, the second part of that work, dedicated to the philosophy of nature

> . . . is, for lack of any more detailed treatment, the fundamental text on this subject, but here we are dealing with that part of the system which was not really of greatest interest to Hegel himself and which, according to the common opinion, is the weakest link of the whole, and is at the same time is the link which aged most quickly.[22]

Against that last remark, one must make a forceful protest: Hegelian philosophy of nature did not have a chance to age since it was an anachronism from the beginning. Let several examples provide evidence for this. Here is Hegel's commentary on the laws of motion of classical mechanics, drawn from the *Encyclopedia*:

> The laws of motion concern *magnitude*, and essentially that of the time elapsed and the space traversed therein; they are immortal discoveries which redound to the greatest honour of the analysis of the Understanding. The next step concerns their *proof* independently of empirical methods; and this proof has also been furnished by mathematical mechanics, so that even a science based on empirically ascertained facts is not satisfied with the merely empirical *pointing out* (demonstration). The *a priori* proof in question rests upon the presupposition that the velocity of a falling body is *uniformly* accelerated; the proof, however, consists in the conversion of the moments of the *mathematical* formula into *physical* forces, into an *accelerating* force imparting one and the same impulse in each unit of time, and into a force of *inertia* which perpetuates the (greater) velocity acquired in each moment of time—determinations utterly devoid of empirical sanction and equally inconsistent with the Notion. More precisely, the determination of magnitude, which here contains a relation of *powers*, is reduced to the form of a *sum* of two independent elements, and in this way, the qualitative determination dependent on the Notion is destroyed.[23]

This passage contains too much syntactic nonsense to make rational explication possible. It does not help to refer back to the definition of terms as established in Hegel's system, for the text concerns Newton's laws of motion and can make sense only when the terms are used with the meanings which they are given in physics. In Hegel's day, those definitions had been well-established for over a century.

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[21] See Karl Popper, *The Open Society & its Enemies* (Princeton: Princeton University Press, 1966), 2: 1–80.

[22] Stanisław Florian Nowicki, Translator's Preface to his G. F. W. Hegel, *Encyklopedia nauk filozoficznych* (Warsaw: Państwowe Wydawnictwo Naukowe, 1990), xviii.

[23] G. W. F. Hegel, *Philosophy of Nature* [1847], §267. Here, A. V. Miller, ed. (Oxford: Oxford University Press, 1970), 57.

Hegel achieves no less comic an effect when he tries to deduce from his philosophy conclusions about physics. So, for example, according to him

> Gravitation is the true and determinate *Notion* of material corporeality, which is *realized* into the *Idea*. *Universal* corporeality essentially sunders itself into *particular* bodies and achieves conclusion with itself in the moment of *individuality* or subjectivity as manifested existence in *motion* which thus is immediately a system of *several bodies*.[24]

A reading of the second part of the *Encyclopedia* provides many such examples. It is very interesting that Hegel did not limit himself only to a "philosophical analysis" of the laws of nature. He also announced empirical predictions which were motivated by his philosophy; he had extraordinary bad luck with respect to the success of those predictions. Here are a few examples of such risky tightrope walking, which I cite from Popper:

> Thus, starting from Plato's *Timaeus* and its number-mysticism, Hegel succeeded in "proving" by purely philosophical methods (114 years after Newton's *Principia*) that the planets must move according to Kepler's laws. He even accomplished the deduction of the actual position of the planets, thereby proving that no planet could be situated between Mars and Jupiter (unfortunately, it had escaped his notice that such a planet had been discovered a few months earlier). Similarly, he proved that magnetizing iron increases its weight, that Newton's theories of gravity and inertia *contradict* each other (of course, he could not foresee that Einstein would show the *identity* of inert and gravitating mass), and many other things of this kind.[25]

Hegel's language can also indispose representatives of the natural sciences towards his philosophy. Here is one more example of Hegel's scientific vacuity (see also Hegel's statement about gravitation cited above):

> Sound is the change in the specific condition of segregation of the material parts, and in the negation of this condition;—merely an *abstract* or an ideal *ideality*, as it were, of that specification. But this change, accordingly, is itself immediately the negation of the material specific substance; which is, therefore, *real ideality* of specific gravity and cohesion, i.e.,—*heat*.[26]

These examples sufficiently discredit the Hegelian philosophy of nature. One can spare oneself a more detailed critique.

7 Evaluation and Conclusions

It is time to attempt an evaluation and the drawing of conclusions.

1. Above all, the Romantic philosophy of nature is more comprehensible (as an historical phenomenon) when one takes into account that it was a reaction to

[24] Ibid., §269 (1). (The emphasis is Hegel's.)

[25] K. R. Popper, *The Open Society*, 2: 27. (In this and the following citation, the emphasis is Popper's.)

[26] Ibid., 28.

a mechanistic understanding of the world. It genetic connections with German mysticism explain well the strategy which that reaction undertook.

2. However—and one must emphasize this—the Romantic reaction was an unsuccessful attempt to create a non-mechanistic philosophy of nature. The sources of this failure must be seen in the fact that that Romantics deluded themselves into believing that there is some other non-mathematico-empirical method of inquiry into the world, through the use of which one can obtain valuable information about nature. To date, no one has found any such method, all the "information about nature" which the Romantics obtained invariably turned out, in the best cases, to be trivial claims, and most often were statements without any scientific value (and sometimes were even statements lacking in any syntactic sense). Hegel's example can serve as a warning to all those who would like to explain nature independently of the natural sciences.
3. The essential component of the "Romantic method" was a frequent appeal to feeling or to esthetic experience. The "sentimental knowledge of nature" does not bring information about nature, but at most information about ourselves, namely about the fact that our minds react to nature fairly readily in a sentimental or esthetic way. By that method, we learn about nature only that it is able to evoke such feelings in us, but that is unproductive information.
4. A rather frequent element of the "Romantic method of inquiry into nature" is irrationalism. An so, for example, in the opinion of Novalis, the proper language for a knowledge of nature is poetry, which is supposed to "heal the wounds" inflicted by reason and which allows one to forget about heartless rational truths. According to Schleiermacher, one must simply abandon any kind of rational thought, and Schlegel would directly declare the superiority of insanity over a normal state "contaminated" by experience and rationality.
5. Reading Romantic philosophers of nature, it is hard to resist the impression that they were looking for a formula for *easy* knowledge. The practice of the natural sciences requires many years of study and arduous preparation; "empathizing" with nature creates the illusion of immediate and (subjectively) certain knowledge. That must be why Romantic philosophers of nature still find many followers.
6. More recently, Edmund Husserl[27] has developed the line of thought first advanced in Schelling's transcendental philosophy. The idea of knowledge without foundations became the basis of Husserl's phenomenology, and the critique of science which he made in *The Crisis of European Sciences*[28] contains many themes deriving from German Romanticism.
7. Having noted the dependence of Marx and Engels on Hegel, one can see that there exists a direct connection between Romantic philosophy of nature and dialectical materialism. The latter is also, to a significant degree, an expression of the tendency to search for an easy and ultimate knowledge about nature.

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[27] See Gilson et al., *Recent Philosophy*, 20.

[28] See Edmund Husserl, *The Crisis of European Sciences and Transcendental Phenomenology: An Introduction to Phenomenological Philosophy*, trans. David Carr (Evanston: Northwestern University Press, 1970).

The verdict on the Romantic philosophy of nature is severe, but is confirmed by the history of the natural sciences. It sees in Romanticism dead ends which are sometimes not even worth discussing.[29] I would like to emphasize that this evaluation directly concerns only Romantic philosophy of nature and not other aspects of Romantic thought. As is known, Romanticism has made great contributions to literature and I do not have the least intention of minimizing them. One must also not undervalue the fact that Romantic thinkers made great contributions to the emergence of modern linguistics and hermeneutics.

The Romantic doctrine of the *universum* and about language as the means of communication between man and the *universum* attracted the attention of thinkers to the question of language in general. It is true that Romantic linguistics was too often a priori, based on imaginative ideas about how the first languages could have developed, which they raised to the level of certainties. But first, Romantic ideas about language created a climate which led to valuable investigations into language. Second, some representatives of that movement themselves made significant contributions to empirical linguistics. Among the latter, one must in particular count *Wilhelm von Humboldt* (1767–1835), who alone was the author of about thirty dictionaries and grammars of various languages.

As for hermeneutics, the central figure in Romanticism was *Friedrich Schleiermacher* (1768–1834). He understood hermeneutics to be the art of properly understanding the speech of someone else. In his opinion, the roots of language reside not only in the historical totality of life, but also the nature of the *universum*, i.e., also in physics. Despite that undoubtedly Romantic understanding of hermeneutics, the role of Schleiermacher in the appreciation of its significance for philosophy was considerable. But both philosophical hermeneutics and the philosophy of language are distinct problems, outside the scope of the philosophy of nature.

Biographical Notes

Jakob Boehme (1575–1624), German theosophist and mystic. He was born in Alt Seidenberg near Görlitz (now Stary Zawidów, near Zgorzelec). Boehme did not create a typical philosophical system but rather a gnostic vision deeply rooted in the mysticism of the Late Middle Ages and the Renaissance. He is known as a precursor of the theosophical movements of the nineteenth and twentieth centuries. In his work, he presented himself as a person who has access to the essence of God and, through God, sees all of creation. Boehme's views exerted a significant influence on the German Romantics (e.g., Schelling).

Johann Gottlieb Fichte (1762–1814), philosopher, born in Lusatia to a poor family. With the help of a local landowner, he was able to attend school. He studied theology, but quickly abandoned his studies and became an adherent of "free study."

[29] See Whitehead, *Science and the Modern World*, 72–90.

In 1794, with the support of Kant, he was given a chair in philosophy at Jena. After 5 years, he lost his position as a result of an article which was thought to be atheistic. When the University of Berlin was opened in 1809, Fichte became a professor there and later dean and rector. Fichte's philosophical works were written while he was at Jena. They include: *Foundations of the Entire Science of Knowledge*, *Foundations of Natural Right*, and *The System of Ethics in Accordance with the Principles of the Wissenschaftslehre*.

Friedrich Wilhelm Joseph Schelling (1775–1854), representative of German idealist philosophy. At the age of 17, he received a master's degree and 6 years later he was given a position at Jena. There, he co-founded the so-called Romantic school. In 1803, he was given a chair of philosophy at Würzburg. His interests evolved in the direction of aesthetics and art and therefore he abandoned Würzburg and became secretary of the Academy of Fine Arts in Munich. Later, he resumed university teaching, first at Erlangen and then in Munich. It is important to mention two of Schelling's works in the philosophy of nature—*First Plan of a System of the Philosophy of Nature* and the *System of Transcendental Idealism*—as well as an outline of his philosophical system, *Darstellung meines Systems der Philosophie* (*Presentation of my System of Philosophy*).

George Wilhelm Friedrich Hegel (1770–1831), German idealist. He came from Swabia. He first studied theology, taking up philosophy only after 1800. He lectured at the University of Jena, where he became docent and later professor. As a consequence of the Napoleonic Wars, he left Jena and moved to Bavaria, where he became first a journalist and then the director of a high school (*Gymnasium*) in Nuremberg. He returned to academic work, lecturing in Heidelberg and later in Berlin. Hegel's entire philosophy is based on the law of dialectic, from which Hegel derived the fundamental law of being. History played an important role in Hegel's philosophy. His main work, *The Phenomenology of Spirit* contains the fundamental ideas of his doctrine. The most complete exposition of Hegel's philosophy is his *Encyclopedia of Philosophical Sciences*.

Appendix: Romanticism in Poland—Between Philosophy and Literature

The beginning of the period of Polish Romanticism in literature is conventionally put at 1822, when Adam Mickiewicz published his *Ballads and Romances*. That work was directed against the Enlightenment attitude formed by positivist and empiricist thought. That collection of poems contains the ballad "Romanticism,"[30] a manifesto of the Romantic movement. In it, Mickiewicz shows the conflict which

[30] Translated by Michael J. Mikoś in his *Polish Romantic Literature: An Anthology* (Bloomington: Slavica, 2002), 20–21.

arose between the partisans of rationalistic Enlightenment ideals and the Romantics. "Put trust in my lens and in my eye," cries the Old Man, beneath whose figure Mickiewicz most likely concealed Professor Jan Śniadecki, mathematician and astronomer and staunch Enlightenment rationalist who called Romanticism "a school of betrayal and contagion." Śniadecki was an enemy of metaphysics and Romanticism. He did not recognize the validity of any speculation or a priori inquiry. In his opinion, knowledge must have an empirical foundation, and the only legitimate method of scientific investigation is induction. However, at the beginning of the nineteenth century, the adherents of Enlightenment ideals were condemned to failure. The change in Polish sensibilities was influenced above all by French Romanticism, with its appeal to the power of feeling and imagination. The Old Man in Mickiewicz' ballad became a symbol of Enlightenment conservativism, which had to retreat before the spirit of Romanticism. The motto of Polish Romantics became:

> Feeling and faith speak more strongly to me
> Than lense and eye of man of learning.

Besides that, Mickiewicz more than once emphasized that the new ideal of knowledge should break free from the old rationalistic rules. In his "Ode to Youth" we read:

> Reach far beyond the range of your sight,
> Conquer what reason can't conquer.[31]

It is worth noting that in Romanticism literature, particularly in Poland, crossed, in a certain sense, into the realm of philosophy. To a significant extent, it fulfilled an ideological function, it shaped attitudes towards life as well as worldviews, and poets played a special role which can aptly be compared to the role of philosophers in ancient Greece—they were prophets, authorities, charismatic leaders of the people.

An interesting example of Romantic creativity, which can be situated on the boundary between philosophy and literature, is the prose poem of Juliusz Słowacki, *Genesis from the Spirit*. It appeared in the so-called mystical phase of the poet's creativity to be an exposition of his philosophical views. Enlisting in the movement critical of Enlightenment ideals, Słowacki dedicated his poem to the Romantic mystic Andrzej Towiański, writing:

> To the one who, neither by words nor by science—but by his arrival and by announcement of God's Work—helped to free my spirit from material bonds and to see into the province of knowledge.[32]

Inspired by reading works about nature and in particular Lamarck's theory of evolution, Słowacki included in his poem a certain kind of "spiritualistic philosophy of nature." A work describing the evolution of the world as a development of the

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[31] Ibid., 18–20.

[32] Translation ours. A complete translation has been published by Kazimierz Chodkiewicz, trans., *Genesis from the Spirit* (London: Chodkiewicz, 1966).

Spirit appeared in 1844, when the poet was on the coast of the Atlantic Ocean. Looking at the ocean—the cradle of life—he wrote:

> O God, Thou lifted me up on the cliffs over the sea that I should recognize the eternal life of my Spirit, and suddenly I became an Immortal, a son of God, the Creator of all visible things, and one of those who living on golden suns and stars voluntarily offer Thee their Love. [§1]

According to Słowacki, the entire process of evolution, as it is observed in nature, came about by the very efforts of the Spirit, which migrated from lower forms to higher, coming at last to man. However, evolution does not end there. The Spirit evolves until the moment when a transformed humanity returns to Christ, from whom the Spirit came.

> . . . everything is created through the Spirit and for the Spirit and nothing exists for material purposes. [§12]

In Słowacki's writings one can see not only explicit traces of the Messianism so popular in Polish Romantic literature, not only the inspiration of Hegelian philosophy of history, but also a similarity between the cosmic vision of evolution and the thesis which would be presented in the twentieth century by the French Jesuit Pierre Teilhard de Chardin.

About Romantic philosophy (and literature) in general it is possible to say, that it cannot be subjected to rational analysis. Metaphysical ideas and a priori speculations, the multitude of metaphors and poetic connections, an almost complete freedom in selection of means—these are the traits which characterize Romantic works. One can suggest that a similar style of doing philosophy has occurred in our times—I speak here of postmodernism. Of course, one should not connect Romanticism directly with postmodernism. It is, however, possible to show certain common characteristics. Postmodernism is a movement directed against, among others, the rationalization of thought and action. A consequence of the reception of the postmodernist attitude is the rejection of generally accepted truth, universal cognitive methods, and general schemata of thought and action.

Chapter 10
The Cosmology of Whitehead: The Universe as Process

1 Sources of the Great System

The thought of *Alfred North Whitehead* (1861–1947) is an exceptional phenomenon in post-Kantian philosophy of nature. Above all, it is authentically philosophical thought, decidedly different from any of the natural sciences. At the same time we here have to do with philosophical thought conducted not only in the context of highly developed classical physics, as was the case with Kant, but growing out of the great revolution which occurred in science at the turn of the twentieth century, the main element of which depended on the transition from classical to contemporary physics. Whitehead's philosophy of nature cannot be treated as some kind of speculative preparation of the way for future achievements in the natural sciences (which seems to be natural in the case of Aristotle and Descartes); nor is it a philosophical search for the presuppositions of the natural sciences or their method (which was the main goal of Kant); Whitehead proposed a speculative system of nature which is supposed to function *parallel to* (but not independently of) the natural sciences. That was an undertaking requiring great intellectual courage, taking into account that the period in which Whitehead created his great synthesis, was characterized by the paralyzing influences of positivism and neopositivism.

Whitehead gave the twentieth century a philosophical system in the style of the great metaphysics of antiquity and of the Middle Ages. But this time, the core of the system was neither ontology nor epistemology nor philosophical anthropology, but precisely the philosophy of nature or cosmology[1] (Whitehead preferred the second term; his main work, *Process and Reality*, had as a subtitle—*An Essay in Cosmology*).

Whitehead's works in the field of the foundations of mathematics (the *Principia Mathematica*, which he wrote together with Bertrand Russell in 1910–1913) greatly influenced his entire view of the world. The rationality of their structures, their construction with the help of functional connectives, respect for the results

[1] In the traditional sense, as a synonym of philosophy of nature. Today, the term cosmology is used almost exclusively as the name of the mathematico-empirical science of the large-scale structure and evolution of the universe.

of intellectual syntheses—all these were elements drawn without a doubt from mathematical habits and they permeate all of Whitehead's writings.

Whitehead brought his mathematical knowledge and his way of thought to the terrain of the theory of relativity, in which he was very interested and which he tried to interpret in his own way. It would not be an exaggeration to say that it was precisely from this that his entire metaphysics of nature arose. The thought of space-time as a set of events, subject to the laws of geometry, made a great impression on Whitehead. Bodies are sets of events; motions—curved lines in space-time. The mutual dependence of events (whether events can, or cannot, come into mutual causal relations) can easily be analyzed in the theory of relativity with the help of relatively simple geometrical tools.[2] The idea of a field, sanctioned in physics by Maxwell's electrodynamics, combined with the idea of space-time, led Einstein to see a gravitational field as a geometrical deformation of space-time (the general theory of relativity). One must supplement that picture with data drawn from quantum mechanics, the other great physical theory which, in the first decades of the twentieth century, revolutionized the scientific view of the world. The thought of "pieces of matter" as building blocks of the world disappears from the picture of the world suggested by quantum mechanics. Matter ceases to be "simply located" in time and space and becomes a field spread throughout space-time.

All of that acted strongly on Whitehead's imagination. Now it was necessary only to rework the "data of science" into a metaphysical structure. From that emerges the category of totality, woven from the mutual relations between the parts, whose only reality is the fact that they are members of the relation. But to that is added one more great idea. This time, it is drawn from biology—the idea of creative *becoming* or growth. Thanks to becoming, the total structure of reality acquires the character of *process*; historicity is its constitutive element. Whitehead called his system *the philosophy of organism* or *process philosophy.*

But I owe the reader a certain warning. The attempt to gather Whitehead's rich and not always unambiguously expressed views (even if the attempt is supposed to be limited to his philosophy of nature) into one not overly long chapter inevitably carries the risk of drastic oversimplification. One particular element of that risk was omission of the evolution of the views of the author both of the early *Science and the Modern World* and of the mature *Process and Reality*. It is necessary, of course, to keep that warning in mind as one reads this chapter, in order to avoid the misimpression that Whitehead's thought can be contained in a static and closed system.

2 Speculative Philosophy and the Empirical Sciences

The question arises: how, in the twentieth century, knowing well both mathematics and the empirical sciences, can one dare to attempt the construction of a "philosophical cosmology"? The undertaking of such a risk is undoubtedly

[2] The so-called conical structure of space-time; see any textbook on the theory of relativity.

motivated by one's conception of philosophy. The beautiful defense of "speculative philosophy" (a name which Whitehead readily uses) can be found on the first pages of *Process and Reality*.[3] From those pages emerge Whitehead's conception of philosophy:

> Speculative philosophy is the endeavour to frame a coherent, logical, necessary system of general ideas in terms of which every element of our experience can be interpreted.[4]

That characterization requires commentary; anyway Whitehead himself did not fail to provide one. For the point of departure of speculative philosophy is *our experience*; it embraces all conscious phenomena: perceptions, desires, moods, thoughts .... All that must be *subjected to interpretation*, i.e.—in Whitehead's formulation—reduced to the role of particular instances of a general scheme. It is important to note: we do not get to the general schema by way of analysis of "our experiences," but—in a certain sense the other way around—those experiences become intelligible only when they find their place in the general schema. Whitehead made frequent reference to Plato, in whose system knowledge takes place "in the descending direction:" from general ideas to individual material things.

The general system is supposed to serve the interpretation of *all the elements* of our experience, i.e., to be *adequate* (Whitehead's expression). Finding even one element which is not interpretable within the system would play the role of a falsifier of the system; the system would have to be rejected.

A general system, according to Whitehead's definition, should be *coherent*, *logical*, and *necessary*:

- *coherent*: Whitehead understands that term as requiring mutual connection of all the elements of a system. Only situating it in a whole gives it meaning. A term isolated from the rest of the system has no meaning. Already at this stage appears the holistic character of Whitehead's thought.
- *logical*: that is, consistent with the principles of logic (in the generally accepted sense of that phrase).
- *necessary*: the system should express what is essential, what is self-explanatory, that beyond which there are no explanations. That requirement places Whitehead's system among the traditional metaphysical systems of the West.

Whitehead goes on to emphasize that his metaphysics has a *rational layer* and an *empirical layer*. The first one constitutes a general system (noted above); the second—a set of given experiences, which are subjected to interpretation in the context of the entire system. The interweaving of these two layers is a feature of all human knowledge.[5]

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[3] Alfred North Whitehead, *Process and Reality: An Essay in Cosmology* (New York: Free Press, 1969).

[4] Ibid., 7. Emphasis mine.

[5] On Whitehead's conception of philosophy, see the chapter "Physique et philosophie, Whitehead," 5–6, in J. Ladrière, *Physique et Métaphysique*; M. Heller and J. Życiński, *Wszechświat i filozofia* (Cracow: Polskie Towarzystwo Teologiczne, 1980), 103–106.

What is the relation of Whitehead's speculative philosophy to the empirical sciences? *Speculative philosophy* is a general system, but it descends to the concrete, to which it gives an interpretation. That interpretation must give an account on the basis of the most detailed nuances of the concrete, in all its dynamic richness, without oversimplifications or stylizations. The *empirical sciences*, on the contrary, are concerned, from the beginning to the end, with situations abstracted from the concrete, idealized and sometimes extremely oversimplified. The sciences, because of their reference to experience, give the impression that they relate to concrete things, but that is a false impression (Whitehead speaks of the "fallacy of misplaced concreteness"). Scientific experiments transform concrete things into numbers (the results of measurement). Reality, i.e., the concrete things, can be present only in an experiment understood as a subjective experience.

3 The Conception of Nature

Whitehead recorded his conception of speculative philosophy in the mature period of his work (in *Process and Reality*, 1929), but he was already doing philosophy in that spirit much earlier. It is impossible to understand the later metaphysics of Whitehead without looking at his conception of nature and his theory of the bifurcation of nature explicated in *The Concept of Nature* (1920).[6] Everything indicates that it was just these ideas that grew in time into a complete philosophical system.

Whitehead writes: *Nature is that which we observe in perception through the senses*.[7] In this definition, and in the concise commentary which follows it, there is great intellectual content. Here is his commentary:

> In this sense-perception we are aware of something which is not thought and which is self-contained for thought.[8]

I understand that as follows: at any moment (but, in the spirit of Whitehead, a moment must be understood as extended in time, see below) we register a set of sensations (sense perception). The word "sensation" here is just right: it suggests above all what we sense, what we gather as one as yet uninterpreted whole (the distinction of certain constituent parts in that whole would already be a kind of interpretation). Further, we register a set of such sensations, i.e., we in some sense admit their content into our consciousness. It is not a cognitive process, but an specific *sense awareness*. Whitehead was the first to draw attention to the fact that just as thought has its awareness (I am aware of my thoughts), it is also necessary to ascribe a certain kind of awareness to the sensations associated with sense cognition.

[6] Cf. Alfred North Whitehead, *The Concept of Nature* (Cambridge: Cambridge University Press, 1971), Chaps. 1–2. All the passages quoted here come from the first two chapters of that book. Emphases mine.

[7] Ibid., 3.

[8] Ibid., 3.

Sense awareness causes us to experience "the whole occurrence of nature." The act of sense perception catches the transitoriness of that of which we are aware:

> It is nature as an event present for sense-awareness, and essentially passing. There is no holding nature still and looking at it.[9]

Nature, as it appears in sense awareness, has still one more trait, namely—as Whitehead says—it is self-contained for thought.

> It means that nature can be thought of as a closed system whose mutual relations do not require the expression of the fact that they are thought about.[10]

In other words: one can think about nature, without taking into account the fact that it is being thought about.

The natural sciences—Whitehead goes on to say—are concerned with the object of sense awareness, but are not interested in sense awareness itself. That last point is the point of departure for philosophy. Speculative thought should interpret the content of sense awareness and, in a certain sense, end its activity there. The reduction of an intellectual construct to a content of sense awareness puts an end to the matter. That content is an ultimate fact, not reducible to anything else. Sense awareness is, for philosophy, the highest authority; it fulfills a function analogous to the function of experiment is physics.

4 The Theory of the Bifurcation of Nature and Its Critique

Now, a new important question arises: what is the cause of our sense awareness? That question has been imposed by the centuries-long philosophical tradition of the West: we register the impressions that come to us and we instinctively think, that they are impressions of something. How does one make the transition from impressions to the things which cause those impressions? From the time of Kant, philosophy was keenly sensitive to that problem.

Whitehead says in the problem so formulated, there is an assumption to the effect that

> nature [can be bifurcated] into two divisions, namely into the nature apprehended in awareness and the nature which is the cause of awareness.[11]

In Whitehead's opinion, that assumption is incorrect. In sense awareness itself, there is nothing which would justify such a "bifurcation." Philosophical thought has to face up to "our experience" in its unbifurcated unity.

Sense awareness at any given time tell us about "the greenness of the trees, the song of the birds, the warmth of the sun, the hardness of the chairs, and the feel of

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[9] Ibid., 15.

[10] Ibid., 3.

[11] *The Concept of Nature*, 31.

the velvet." At the same time, we believe that the cause of all that is "the conjectured system of molecules and electrons which so affects the mind as to produce the awareness of apparent nature."[12] In such a formulation, the first domain (the greenness of the trees, etc.) is an illusion created by the mind, the second domain (molecules and electrons) is an hypothesis of modern physics. Thus, Whitehead writes, "there would be two natures, one is the conjecture and the other is the dream."[13]

At the foundations of the myth about the bifurcation of nature lies the doctrine, deriving from Aristotle, about substance and its properties: we know the properties through impressions, but their real substrate is a substance. In Whitehead's opinion, the first blow to that conception was struck by the theories of light and sound proposed already in the seventeenth century. Physics had then established beyond any doubt that bodies emit signals which are transformed by our senses into impressions. Electromagnetic waves strike our eye, but we do not see electromagnetic waves. A visual impression is the result of the transformation of that signal into perceptual material. In that entire process, there is no trace of anything which could be identified with a substance-like substrate of a property. And thus, for example, there is no substance as a substrate of color, for there are no colors. Color is the result of the reaction of an eye to one length of electromagnetic wave rather than to another. The substrate turns out to be a fictive product of our thought; and indeed of a thought burdened with the habits of tradition. Whitehead does not hesitate to call that fiction a "metaphysical chimera."

But Whitehead is also far from a narrow phenomenalism, i.e., from the reduction of all reality to the level of sense phenomena. He only wants to emphasize that at the point of departure for philosophizing we must take into account only that which we experience through sense awareness. Sense awareness stands us up against the totality woven from the "all-embracing relations" between things which are sensed. The point is that:

> [to perceive] the ... redness and warmth of the fire in one system of relations with the agitated molecules of carbon and oxygen, with the radiant energy from them, and with the various functionings of the material body.[14]

(It follows from the context that Whitehead here has in mind the body of the perceiving person.) The redness and the warmth of a fire belong to the impressionistic side of bifurcated nature; the agitated molecules and radiant energy—to the fictional side, which is supposed to cause impressions. Such a bifurcation can be eliminated, but only by treating everything as a "relational totality."

Part of the relations constituting that totality have a spatial and temporal character.

[12] Both passages, ibid., 31.
[13] Ibid., 30.
[14] Ibid., 32.

> The perceived redness of the fire and the warmth are definitely related in time and in space to the molecules of the fire and the molecules of the body.[15]

Temporal relations, in particular, have great significance for Whitehead. He will write, among other things (remarking that this is a metaphor) that, "time would apparently have deeper roots in reality than has nature."[16] We can, therefore, imagine for ourselves thoughts ordered in time, despite the fact that those thoughts were not a part of nature.[17] Let us content ourselves with the statement that Whitehead chose to emphasize that transitoriness belongs to the very essence of nature by means of a metaphor. I cannot allow myself to go into detail on the subtlety of Whitehead's system; I refer the interested reader to the philosopher's original texts.

5 Space and Time

We noted above that among the relations, from which the totality which Whitehead calls nature is woven, the relations of space and time are particularly important. Let us now take closer look at Whitehead's views of space and time.[18]

Whitehead's position on the subject of space and time stands out for its originality from among all the better known views on this topic. Whitehead considers that the concrete objects with which we have to do in sense experience are not points or moments, but spatial *volumes* and temporal *intervals*. However, neither volumes nor intervals can be treated as "pieces" of space or time. Let us look at the problem using the example of spatial volumes.

Of course, volume is—in a certain sense—a spatial part, but "in the sense that each part is something from the standpoint of every other part" In more detail:

> . . . if A, B, and C are volumes of space, B has an aspect from the standpoint of A, and so has C, and so has the relationship of B and C. This aspect of B from A is of the essence of A. The volumes of space have no independent existence. They are only entities as within a totality; you cannot extract them from their environment without destruction of their very essence.[19]

Whitehead here appeals to Leibniz and says, "every volume mirrors in itself every other volume in space."

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[15]Ibid., 33.

[16]Ibid., 34.

[17]For example we can imagine one of Milton's angels with thoughts succeeding each other in time, who does not happen to have noticed that the Almighty has created space and set therein a material universe. (Ibid., 35)

[18]Whitehead treats this topic in *An Enquiry Concerning the Principles of Natural Knowledge* (Cambridge: Cambridge University Press, 1925). See also Chaps. 3 and 5 in *The Concept of Nature*. In this chapter, I follow the simplified presentation of the problem as presented by Whitehead in *Science and the Modern World* (1925).

[19]Cf. Whitehead, *Science and the Modern World*, 64. [Citations from Mentor edition (New York, 1948).]

Space is not a simple placing of various volumes next to one another; for the concept of space, what are important are relations of different volumes which are superimposed on one another. Volume should not be imagined as space broken up into parts; quite the contrary—space is an hierarchical system of relations between various volumes.

A parallel analysis can be made for temporal intervals.

That is the context in which appear Whitehead's arguments against the concept of the *simple location* of matter as it functioned in the earlier interpretation of classical physics. How should one understand that concept? "Simple location" in time and space includes the following intuitions:

> as regards time, if material has existed during any period, it has equally been in existence during any portion of that period. In other words, dividing time does not divide the material. . . . in respect to space, dividing volume does not divide the material. Accordingly, if material exists throughout a volume, there will be less of that material distributed through any definite half of that volume.[20]

Whitehead cannot accept the idea of simple location; it remains in fundamental disagreement with the general perspective of his system. It is not possible to speak sensibly about pieces of space and time without regard to the totality which is, for them, their necessary environment.

Whitehead discerns the confirmation of his views in the development of modern physics, especially quantum mechanics; according to the latter, the wave function describes matter existing rather as "a melody" than as the bricks from which one builds a building. What is more, Whitehead links the development of modern materialism with the functioning of the term "simple location" in the interpretive layer of classical physics. The repudiation of that term by modern physics, in Whitehead's opinion, sentences materialism to banishment from the realm of the modern philosophy of nature.[21]

6 The Metaphysics of Process

In the present chapter, we are interested in Whitehead's philosophy of nature, but it is appropriate to put the philosophy of nature into a general metaphysical context: all the more because Whitehead's metaphysics strongly emphasizes themes from the philosophy of nature. I will, however, do that only in outline, without any claim to completeness. Whitehead's metaphysics is too rich to fit in its entirety into the final paragraphs of a chapter.[22]

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[20] Ibid., Chap. 4, 50–51.

[21] The justification of these views is one of the main themes of *Science and the Modern World*.

[22] The most complete exposition of Whitehead's metaphysics as a fully mature system is found in his *Process and Reality*.

The considerations thus far have surely suggested to the reader that Whitehead's thought receives it general tone from two ideas: (a) the idea of *totality*, defined without remainder as the system of relations between its parts (reality as an organism); (b) the idea of the passage of time, *temporalization*, which leads to the formulation of reality as a *process*. Let us give those ideas slightly more detailed analyses.

The primordial elements of space and time are—as we have seen—volumes and temporal intervals. But time and space are only substructures of the general structure of reality. For, analogically, it would be possible to ask, what are the "primordial elements" of organic reality. Whitehead's answer is similar to the philosophical vision of Leibniz in that Whiteheadian monads, which he calls *actual entities*,[23] are not closed worlds, synchronized with one another by the power of a pre-established harmony, but—on the contrary—their entire essence is reduced to the fact that they enter into relations with other actual entities. Whitehead says that the essence of actual entities is *prehension*, or the entry into relations with other actual entities (the Leibnizian reflection of the whole world in one monad). Here we explicitly have a clear metaphor for knowledge: an actual entity somehow *observes* other actual entities; that observation (or prehension) is its material.

One should not imagine actual entities as lasting "components" of reality; they are "elementary expressions" of the process of the passage of time. When, in the process of prehension, those actual entities reach *satisfaction*, they are absorbed by the next actual entities, which bear in themselves traces—by means of prehension—of the earlier actual entity. That is how the process of the universe operates; that process is a constant *becoming*.

Whitehead understands the process of becoming somewhat in the spirit of the metaphysics of Aristotle, as a transition from possibility to act, but only "somewhat," because the idea of the actualization of an actual entity here is entirely his own. An actual entity can *grow*, or strive for its own satisfaction (Whitehead here purposely uses terms borrowed from the field of changes in living organisms), in two ways: Either as a result of the prehension of other actual entities, or as the result of the prehension of *eternal objects*. An eternal object is pure possibility, which causes an actual entity to be what it is, while the ingression of the eternal object into an actual entity occurs. The ingression takes place when the eternal object is prehended by the actual entity. Whitehead writes, "the metaphysical status of an eternal object is that of a possibility in relation to an actual object."[24] An actual entity becomes itself by the realization of one among infinitely many possibilities: "actualization is a selection among possibilities."[25] But the eternal objects also have a "relational essence," i.e., the essence of each eternal object is a system of relations towards other eternal objects.

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[23] Sometimes, Whitehead uses other terms instead of "actual entities." For example, in *Science and the Modern World*, he uses the term "actual occasions."

[24] *Science and the Modern World*, 144.

[25] Ibid.

Reality as process is constant becoming. That becoming is characterized by a genuine *creativity*, i.e., in its course *appear* ever new forms and contents. There arises the question, characteristic for all post-Parmenidean metaphysics, which acknowledges that being cannot come to be from non-being: What is the source of the realization of essentially new possibilities? Whitehead's answer is the classic one: God. The logic of the system requires acceptance of a being of maximal actuality (or a Greatest Actual Being), which would be the source of all possibilities. In that context, eternal objects can be considered as the counterpart of Augustine's eternal ideas (i.e., ideas in the divine mind). Whitehead understands the process of the actualization of beings (or, the process of creation) as God's *limitation* of the infinite field of possibilities to the concrete thing which comes into being.

But besides God*'s antecedent nature*, understood as the source of all possibilities, God also has a *consequent* nature, understood as kind of "feedback" between the becoming of the world and God Himself. God somehow includes Himself in the process of the development of the world, thanks to which, in some sense, one can also speak of the becoming of God.

7 Some Remarks in Conclusion

I should emphasize once again that this chapter—perhaps more than the others—is rather a juxtaposition of "selected problems from Whitehead" than a systematic exposition of his philosophy. It is important to keep in mind the particular brevity of the presentation of Whitehead's metaphysics. The originality of that thinker, the all-embracing character of his system, his distinctive terminology (created almost from the foundations) would cause any attempt at a more comprehensive presentation of process philosophy to exceed the bounds of the present chapter.

I mentioned in the introduction to this chapter that the philosophy of Whitehead was inspired by the achievements of twentieth-century mathematics and natural science. After even a cursory familiarization with the views of the author of *Process and Reality*, it is easy to understand that, for Whitehead, the significance of the theory of relativity and of quantum mechanics goes far beyond the function of inspiring adequate ideas. In Whitehead's thought there are no "non-intersecting planes" of philosophy and of natural science. The natural sciences are a particular case—of course, stylized, idealized, and, with the help of abstraction, stripped of the traits of the individualized concrete object—but nevertheless situated in a general metaphysical schema. A metaphysics which would exclude the natural sciences from its schema, or which would proclaim that those sciences (as a result of the use of different intellectual tools) have no relation to philosophy, would be sterile or simply false.

Whitehead's system is an interesting attempt to show how metaphysics can grow from the natural sciences and later assimilate them into its organism. Whitehead was deeply convinced, that the reverse process would also occur, that his philosophy would lead to a reinterpretation of certain branches of physics (especially the theory of relativity), and—perhaps—would push the empirical sciences to develop in new directions. Despite certain attempts undertaken in that spirit by Whitehead himself, the natural sciences remain indifferent to such attempts and nothing indicates that that situation will change. I think that Whitehead himself would recognize that fact as the most serious argument against his philosophy.

Biographical Notes

Bertrand Russell (1872–1970), British philosopher and mathematician. He was born in Trelleck, England. He was first educated privately, but studied at Cambridge in 1890–1893. After several years study, he was appointed lecturer at Cambridge, but was dismissed for pacifist agitation during World War I. He went to Japan, where he ran an elementary school. After his return to Oxford, he published his chief works in the philosophy of mathematics: *Principles of Mathematics, Principia Mathematica* (together with Whitehead), and works on realism: *The Problems of Philosophy*, *Our Knowledge of the External World*, *The Analysis of Mind*, and *The Analysis of Matter*. At Cambridge, Russell also studied mathematical logic. He proposed a problem, now known as the Russell paradox, which is one of the classical paradoxes of set theory. In order to avoid the paradox, he created the logical theory of types.

Alfred North Whitehead (1861–1947), British philosopher and mathematician. He was born in Ramsgate, England. He studied classical philology and mathematics. In 1884, he received his doctorate at Cambridge University. In 1884–1910, he taught mathematics, first at Trinity College and then in London. In 1924, he took a position as professor of philosophy at Harvard University in the United States. He is noted for his co-operation with Bertrand Russell and for their three-volume work *Principia Mathematica*, which lays the logical foundations of mathematics on the basis of set theory. In 1929, Whitehead published *Process and Reality*, a groundbreaking work in metaphysics. Other well-known works of Whitehead include: *Science and the Modern World* and *Religion in the Making*. Whitehead's academic life can be divided into three periods: until 1914 he worked on mathematics and logic; in 1914–1924 he dedicated himself to work in physics; and in 1924–1947 he turned to metaphysics and the role of metaphysical ideas in history.

Appendix: Process Philosophy and Its Continuation in Modern Thought

Process and Reality is a work in which Whitehead undoubtedly made a breakthrough in metaphysical thought. The conception of reality as a *process* became a fertile idea which has found many adherents. It is, however, worth taking a look at the very idea of *processualism*, which one can find even among the ancient Greeks. One can take *Heraclitus of Ephesus* as the inventor of the process approach in philosophy. In his work *On Nature*, he presented the world as a constant struggle between forces, based on the continual contention of opposites. His well-known saying that "one cannot step into the same river twice" shows that one should not understand the world as a static creation—nothing is fixed, everything is in the *process of change* (*panta rhei*—everything flows). In radical opposition to the views of Heraclitus stood the static view of *Parmenides* as well as the views of the *atomists*—*Leucippus*, *Democritus*, and *Epicurus*—according to whom the world is made up of immutable atoms.

In the twentieth century, process philosophy has returned, thanks to the above-mentioned work of Whitehead. Of course that does not mean that there has been no mention of it since the time of Heraclitus. One can find strong elements of process thought, among other places, in *Henri Bergson*. His works influenced Whitehead's thought and that of the representatives of his school—Charles Hartshorne and Paul Weiss. Hartshorne, referring to Whitehead's process philosophy, devotes a particularly large amount of space to problems in the field of the philosophy of God. He develops a panentheistic conception of God, in which God is both the ontic foundation of the rationality of the world and the immanent "companion in the sufferings of man."

Whitehead's philosophy was an inspiration in intellectual circles, especially in the United States, Canada, and Australia. Whitehead himself spent 23 years in the United States and his influence is greatest there. Most of the works in the field of process philosophy have been published in the United States. One can even notice a growth of interest in this field; it is quite popular contemporary American philosophy. It is hard, however, to speak about a concrete philosophical school, for thought inspired by Whitehead's philosophy spreads so broadly that it often oversteps the bounds of philosophy. One can even speak of the phenomenon of the institutionalization of process thought in the United States, which began after Word War II. Institutions promoting Whitehead's thought appeared. Later, similar organizations appeared also in other countries. On the web-site of the University of Saskatchewan Process Philosophy Research Unit we read: "USPPRU is unique in the Canadian university system. It comprises a group of interdisciplinary researchers, who have been actively engaged in investigating process philosophy and its relationship to education, ecology, culture, science and society." It is worth also mentioning several other institutions which are developing the idea of process philosophy. They are: The Center for Process Studies, founded in 1973 at the Claremont School of Theology; the International Process Network, an institution consisting of fifteen organizations around the world; the Association for the Process Philosophy of Education (APPE); and the Australian Association for Process Thought, founded in 1996. Although nearly all of those institutions take as the motto for their work some passage from a famous work of Whitehead, one must emphasize that those organizations, in their work, go far beyond what can be called process philosophy in the strict (Whiteheadian) sense of the term. One should speak rather about philosophical inspiration on the basis of which appeared a trend of *process thought*, one which is present not only in philosophy, but also in many other fields of science and social life.

Chapter 11
Popper's Open Universe

1 The General Outline of Popper's Thought

The thought of *Karl Raimund Popper* (1902–1994) is a phenomenon symptomatic of the twentieth century. It grew almost entirely out of the atmosphere which surrounded the empirical sciences. While Whitehead drew inspiration for his philosophy from the natural sciences and had the ambition to create a system in some sense consistent with the results of those sciences, it was not Popper's intention in general to create any philosophical system at all and in particular it was not his intention to create a philosophy of nature. Popper from the beginning was interested in science, its methods, and its assumptions. He took seriously the description of the world that were being given by scientific theories and did not think that any philosophy independent of the empirical sciences could add anything valuable to our understanding of the world. Popper's first period of creative activity could be called his *methodological phase*. Already during that phase, it became clear that it would not be possible to speak about a sound methodology without the intrusion of authentically philosophical thought. Philosophical elements turn out to be indispensable both during the discussion of the foundations which are implicit in the empirical method and in the process of clarifying the limits of that method. Above all, *justification* of the empirical method is, by its very nature, a philosophical endeavor. All that led Popper to ideas which place him in the ranks of the most important philosophers of our times.

Also not without influence here were Popper's philosophico-political and socio-moral analyses which the situation of the Second World War and his experience of it forced him to undertake. In two great works from that period (*The Poverty of Historicism* (1944–1945) and *The Open Society and its Enemies* (1945)), Popper dealt very critically with various forms of totalitarian ideology and he declared himself in favor of an "open society," building the common good of its members not on the basis of irrational ideologies, but making use of the method of "rational criticism." The indispensability of philosophy is even more clear in historico-social analyses than on the terrain of methodology. All social and moral decisions lacking a "philosophical base" transform themselves into irrationalisms which lead easily to totalitarianism.

It is necessary to discuss the "philosophical base" in detail. From it arose Popper's ideas about such traditional philosophical problems as: epistemology (*Conjectures and Refutations* (1963) and *Objective Knowledge* (1972)), philosophical anthropology (*The Self and its Brain* with John C. Eccles (1977)), and philosophical cosmology (*The Open Universe* (1972)). All of Popper's ideas are situated precisely in the context of the natural sciences. It is not only a philosophy "open" to the natural sciences, but a philosophy which would be simply impossible without those sciences.

A fuller understanding of Popper's thought requires awareness of the fact that his thought was formed in the Viennese atmosphere of the neopositivism of the 1920s and early 1930s. From the beginning, Popper opposed the neopositivist ideology, which limited the "field of rationality" exclusively to the domain of the empirical sciences. In Popper's opinion, the empirical method is the most successful application of rationality, but it is not the only one. What is more, rationality from outside the empirical realm is a necessary condition of the rationality of the empirical method itself. All of Popper's thought, and the style of his argumentation are marked by a emphasis on arguing against the logical empiricism of the Vienna Circle. The decline of neopositivism was a result of the general philosophical situation of the second half of the last century, but that situation was, to a significant extent, formed by Popper's thought.

Popper's philosophical cosmology is not limited to his theory of the "open universe." As a result of a precise fusion of Popper's thought with the natural sciences, elements of that philosophical cosmology are present in almost all of his analyses. Even in his historico-social thought, the rationality of the empirical method is a model of how to conduct inquiry (although it is a model that cannot be followed literally). There is no way to present Popper's views on the philosophy of nature without giving at least a brief account of his views in the philosophy of science; I will devote to it one brief paragraph. It will also be necessary to reserve some space to a look at Popper's views of philosophy and its role in the process of understanding the world. Beyond that, we will consider only those aspects of Popper's thought which would traditionally be called a philosophical cosmology.

2 Popper's Intellectual Morality

How can one obtain certain knowledge? There is none in intellectual speculation—the critique made by Locke, Hume, Kant, and others showed that, and the history of philosophy, beginning with the pre-Socratics, confirmed it. Nor can one find a road to such knowledge in mere experience—the rugged adventures of nineteenth and twentieth century positivism revealed that clearly enough. Is the situation hopeless, then, one from which the only way out is irrationalism? It is true—in Popper's opinion—that there is no ultimate foundation, building on which it would be possible to avoid the danger of error. The danger of error is always a possibility. It creates a situation of openness to criticism. *Rationalism*, i.e., the construction of knowledge and activity on *rational grounds* is not based on the establishment of ultimate certainties once and for all, but on the constant exposure to criticism and self-criticism. Popper's philosophy has aptly been called *critical rationalism*.[1]

At the foundation of Popper's critical thought lies the *principle of falsification*, formulated by him at an earlier period in his work (*The Logic of Scientific Discovery* (1934)). It arose in connection with Popper's opposition to *inductivist theories of science*. According to him, the empirical sciences do not develop by the method of simple generalization of the many results of experience (which could, for example, occur according to Mill's Canons), but by the method of bold conjectures which are then put to the test by confronting their predictions with the data of experience (the *hypothetico-deductive method*). This kind of testing plays the role of a *demarcation criterion*, by which one can distinguish science from non-science. The theory is scientific if its predictions can refuted (falsified) by the results of experiments. There can be no discussion of a theory which is confirmed by everything; such a theory is unscientific. The essential content of the falsification principle can be reduced to that.

Schema of the Hypothetico-Deductive Method according to Popper

	Theory	
Formulation of Hypothesis	→	Deduction of Consequences
↑		↓
Problem situation, its initial recognition		Confrontation of predictions with experiment

The falsification principle must be followed in the empirical sciences, but a certain "moral," implicit in that principle, extends to all spheres of thought: when a doctrine makes itself immune to criticism, it cuts off all discussion in advance and it not worthy of further consideration.

From this kind of "intellectual morality," certain conclusions follow. Among others: (a) no thought can appeal to authority (and especially not to force!) as arguments in its favor; (b) all thought must be pluralistic; only in a climate of many competing views (theories) is discussion and authentic criticism possible.

[1] See Renée Bouveresse, *Karl Popper ou le rationalisme critiqu*e (Paris: Vrin, 1981), 9–10. There are already many books and articles dedicated to Popper. In this chapter, I make ready use of Bouveresse's book. That book differs from the other by its degree of insight and its great faithfulness to the texts of Popper himself.

The method of critical rationalism has hitherto found its most perfect expression in the method of the empirical sciences. Popper sees more than just an analogy between biological evolution and the development of the sciences. In both cases, the same strategy—the strategy of trial and error, elimination of the less fit, the struggle for survival, i.e., the method of rejecting everything that can be rejected.

> All this may be expressed by saying that the growth of our knowledge is the result of a process closely resembling what Darwin called "natural selection"; that is *the natural selection of hypotheses*: our knowledge consists, at every moment, of those hypotheses which have shown their (comparative) fitness by surviving so far in their struggle for existence; [. . .].[2]

Or, more concisely: "From the amoeba to Einstein, the growth of knowledge is always the same."[3] In the context of these views, it would be possible to speak about an *evolutionary theory of science* (or, more generally: *of knowledge*). Popper significantly developed that theory (modifying some of his earlier statements) in discussions with Kuhn, Lakatos, and other philosophers of science concerning the rationality of science and its development. There is not, however, space here for a discussion of that issue; the interested reader will have to turn to the broad literature on this topic.[4]

And finally the key question on which all of critical rationalism depends: Are there any rational grounds for recognizing the method of critical rationalism as the only correct method of thought and action? In other words: Can critical rationalism be critically and rationally justified? The answer, of course, must be negative: It is not possible to use rational arguments to convince someone who opposes rationality from the start. The limits of rationality must be sought, not in its results, but in its assumptions.

The great effectiveness of the method of critical rationalism could be taken as a kind of justification of the method itself, but—speaking precisely—effectiveness is a part of rationality, and if someone does not believe in effectiveness, then that would not constitute any kind of justification for him. A choice of the method of critical rationalism (and the empirical method as its most effective incarnation) is *the choice of a certain value* and so, in its essence, *a moral choice*. European science finally made that choice at the turn of the eighteenth century, and European philosophy made it much earlier. That choice contains the decision not to appeal to force. Here Popper's philosophy of science crosses over into his philosophy of history and society.

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[2] *Objective Knowledge* (Oxford: Oxford University Press, 1972), 261.

[3] Ibid.

[4] For example, Bouveresse, *Karl Popper*, Chap. 3, especially 84–85; S. Amsterdamski, *Between Experience and Metaphysics: Philosophical Problems of the Evolution of Science* (Boston: Reidel, 1975).

3 Antiessentialism and the Defense of Philosophy

As we saw, for Popper, the realm of rationality is not limited to the domain verified by the *empirical* method (as the neopositivists insisted), but extends far beyond it. Beyond the limits of empirical rationality, Popper finds a place for genuinely philosophical inquiry.

Popper very decidedly defended the possibility of metaphysics against the neopositivist claim that metaphysical statements contain only emotions and lack cognitive content. Such a claim is itself a kind of metaphysics; wanting to avoid philosophy, one falls into its trap.

The Vienna neopositivists, following Wittgenstein,[5] considered philosophical statements (i.e., statements which are neither empirical statements nor tautologies) to be simply meaningless; and consequently, philosophy is not able to solve any problems; it can, at most, by linguistic analysis, show that a given problem is merely apparent, that it is based on disguised syntactic nonsense.[6] In reply, Popper admits that problems traditionally considered to be metaphysical can indeed often be reduced to grammatico-linguistic errors; there are, however, genuinely metaphysical problems, e.g., whether we have knowledge about things from our senses? Whether induction can lead to valuable knowledge? Whether there is only a potential infinity or also an actual one? And problems connected with moral principles.[7]

It is, however, obvious, that the falsification principle cannot be applied to any of those problems. Is it possible, despite that fact, to maintain that those problems are meaningful? The criterion of falsifiability, in its precise sense, applies only to empirical theories; in philosophy, one can, at best, understand it in a very broad sense. Answers to philosophical questions can only be hypothetical, but they allow genuine discussion: they can be criticized on the basis of their coherence, their ability to unify hitherto disparate problems, their fertility, their avoidance of entanglements in difficulties. Philosophical statements can be subjected to real criticism—as Popper says—in the concrete *problem situation*.

What is more, one can speak of a certain *content* of philosophical propositions. That can be a *logical content*, defined as the collection of all those propositions which are the logical result of the given proposition (the collection of the consequences of the proposition), or the *informational content*, which Popper defines as the collection of propositions excluded by the given proposition. The more the given proposition (or theory) excludes, the more informational content it has.[8]

[5] Wittgenstein laid out his position in the *Tractatus Logico-philosophicus* (London: Routledge & Kegan Paul, 1955).

[6] See the more detailed critique of neopositivism in my book *The World and the Word: Between Science and Religion*, trans. Adam Chester Kisiel (Tucson: Pachart, 1986), 63–72.

[7] Popper presented these as examples of philosophical problems in a discussion with Wittgenstein which took taken place at Cambridge in 1946; cf. Karl R. Popper, *The Unended Quest: An Intellectual Autobiography* (Fontana, 1976), §26, 122–124.

[8] *The Unended Quest*, 26.

A philosophical theory with greater logical and informational content should be recognized as more perfect than a theory with less logical and informational content.

All that brings it about that, just as it is possible to draw boundaries between falsifiable empirical theories and non-falsifiable ones, it is also possible to distinguish philosophical theories that can be perfected by criticism from those which are completely insensible to any criticism. The latter group contribute nothing to philosophy. Although philosophy is not falsifiable, it certainly is *criticizable*.[9]

That defense of philosophy does not mean that Popper accepted traditional metaphysics without reservations. On the contrary, Popper battled, even to excess, against disputes about words and their meanings. As is well-known, traditional (e.g., Aristotelian) metaphysics ascribed to certain concepts (or terms) the function of expressing intuitively obtained knowledge about the *essences of things*. Popper called this kind of doctrine *essentialism* and treated it as equivalent to disputes over words.[10]

In opposition to the pseudoproblems created by essentialism, Popper valued *factual problems*; only they enrich knowledge. And the factual is what, in some sense, agrees with reality. Tarski's definition of truth provided Popper with the philosophical motivation for that view. That definition, to be sure, concerns only formal languages, but it shows that it is possible to speak meaningfully of the agreement of some propositions with other propositions which represent the reality (or sphere) about which the earlier propositions speak. Popper understood that definition to be a kind of rehabilitation of the classical definition of truth (agreement of statement and reality) and recognized himself to be greatly indebted to Tarski in the field of philosophy.[11]

4 Popper's Three Worlds

The Popperian understanding of truth presupposes realism. In Popper's opinion, the affirmation of realism—like all statements outside the realms of logic and (finite) arithmetic—cannot be proven (is unprovable); in contrast to empirical statements, it is not refutable, "but it is arguable, and the weight of the arguments is overwhelmingly in its favor."[12] Realism, and the possibility of expressing true statements, guarantees the possibility of *objective knowledge*. However, Popper understands objectivism in his own way, not as the opposite of the subjective knowledge of the individual, but as knowledge that is communicable to others or is intersubjectively meaningful. For we are not talking here about knowledge as an individual possesses or does not possess it, but about the knowledge which society has at its disposal.

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[9]See Bouveresse, *Karl Popper*, 66–68.

[10]For more, see ibid., Chaps. 6–7.

[11]See Popper's essay "Philosophical Comments on Tarski's Theory of Truth" in *Objective Knowledge*, 319–340.

[12]*Objective Knowledge*, 106.

Robinson Crusoe on an uninhabited island cannot have objective knowledge. In the classical epistemology (of Kant, Russell, and others) the topic is always the knowledge of an individual subject, but Popper speaks about his conception figuratively as about *an epistemology without a cognizing subject* and presents it with the help of the metaphor of *three worlds*.

World 1 is the world of physical objects and physical states. *World 2* is the world of states of consciousness and states of mind, or, perhaps, of behavioristic predispositions to act. *World 3* is the world of the objective content of thought, and in particular of scientific and poetic thought as well as of works of art.[13] In other words, World 1 embraces, as Kant would say, things in themselves things not directly accessible to human knowledge, World 2 is the world of the subjective knowledge of particular people, and World 3 contains Popper's objective knowledge.

> Among the inmates of my "third world" are, more especially, *theoretical systems*; but inmates just as important are *problems* and *problem situations*. And I will argue that the most important inmates of this world are *critical arguments* and what may be called—in analogy to a physical state or to a state of consciousness—*the state of a discussion* or the *state of a critical argument*; and, of course, the contents of journals, books, and libraries.[14]

World 3 is created by human beings, but as soon as it arose, it obtained a certain autonomy, secured its independence of human minds, and became something objective. It is possible to send research expeditions into the depths of World 3, just as we send them into the remote reaches of unknown lands. The philosophy of science is nothing other than research into those realms of World 3 which are inhabited by the products of science, scientific theories, scientific methods, etc.

Popper recognizes the similarity of his theory of World 3 with the ideas of Plato, with Hegel's Objective Spirit (though there are also many differences here) and in particular with Bolzano's theory of the world and with Frege's conception of the objective content of thought.

5 Popper's Philosophical and Cosmological Indeterminism

In the "philosophical phase" of his work, Popper created a kind of *philosophical cosmology*. It is the result of taking into consideration the presence of World 3 in the universe. World 3 is a product of the evolution of the (physical) universe, but when World 3 appeared in the universe, it introduced a "new quality," and established a new kind of indeterminism, bringing about—as Popper says—the *openness* of the universe.[15]

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[13] Ibid., 106.

[14] Ibid., 107.

[15] See, K. R. Popper, "Indeterminism in Quantum Physics and in Classical Physics," *The British Journal for the Philosophy of Science* 2 (1950): 117–133 and 3 (1950): 173–195. Those ideas were later developed in the form of a book, *The Open Universe*, which became the second volume of *The Postscript to the Logic of Scientific Discovery*.

Popper is a decided opponent of determinism in its various forms. Even classical physics, in Popper's opinion, does not ascribe an exact determinism to nature. Popper concedes that there are *prima facie deterministic* theories in physics, i.e., those theories which allow one to determine—to any degree of approximation—any state of a closed (isolated) physical system from an exact knowledge of its initial conditions. Such theories include: classical mechanics, classical electrodynamics, the special theory of relativity, and others. The object of Popper's attack is what he calls *scientific determinism*, which postulates the possibility of predictions *on the basis of the rational procedures* which are obligatory in the sciences. To the extent that determinism *prima facie* requires unambiguous predictions of the behavior of the system under investigation *in principle*, scientific determinism must be characterized by a certain kind of *realism*. In the name of that realism: (a) the investigator who makes the predictions should not be "artificially abstracted" from the system, but he has to be within the system, and has to be bounded by the laws on the basis of which he makes the predictions; (b) also in the name of that same realism, the investigator can have a familiarity with the initial data to any *arbitrary*, but always to a *limited*, degree of precision. Those two features must be understood to be the defining features of "scientific determinism."

In Popper's opinion, the work of Jacques Hadamard, completed in 1898,[16] provides a physical argument against scientific determinism. In that work, Hadamard proved that there exist, in classical mechanics, movements characterized by a certain kind of *instability* consisting of the fact that despite any arbitrary, but *finitely exact*, knowledge of initial conditions, it is not possible to make an unambiguous prediction of the future states of a moving particle.[17]

Hadamard's results have to be supplemented (Popper does not do this) by newer results in research into various kinds of stability and instability of systems. It turns out that the phenomenon discovered by Hadamard is quite common; that type of unstable motion is now called *deterministic chaos*. Research into deterministic chaos is conducted using the methods of the mathematical theory of dynamics systems,[18] that phenomenon was given a rich interpretation in the catastrophe theory of René Thom,[19] and was to receive numerous applications in non-linear thermodynamics developed by Ilya Prigogine and his school.[20] All those results (although Popper himself, in writing *The Open Universe*, did not indicate that he was aware

[16] J. Hadamard, "Les surfaces à courbures opposées et leurs lignes géodésiques," *Journal des Mathématiques Pures et Appliquées* 4 (1898): 27–73.

[17] Speaking in the language of today, Hadamard proved the instability of motion on geodesic lines of surfaces of negative curvature.

[18] See, for example, the excellent textbook: M. W. Hirsch and S. Smale, *Differential Equation, Dynamical Systems and Linear Algebra* (New York: Academic Press, 1974).

[19] R. Thom, *Structural Stability and Morphogenesis: An Outline of the General Theory of Models* (Reading, MA: Benjamin Cumming, 1975).

[20] I. Prigogine and I. Stengers, *Order out of Chaos* (New York: Bantam, 1984).

of them) confirm Popper's conclusion: scientific determinism, even in classical physics, cannot be maintained.[21]

However, the analysis of the theories of physics provides Popper only with secondary arguments against scientific determinism. The primary arguments are the paradoxes which arise when the researcher tries to predict his own future knowledge. (Those paradoxes become even more evident when the researcher is replaced by a machine which predicts its own states.) If the researcher were capable of predicting his own future knowledge, let us say a 1000 years hence, he would possess that knowledge even at the present moment, which would destroy the prediction in embryo. Popper cites, and gives a detailed analysis of several versions of that type of paradox.

The result of all those considerations is the following: although the physical universe was in itself a *prima facie* deterministic system, once World 3 was introduced into it, it becomes an *open universe*. The placement of man into the universe, together with the science which he creates, requires one to go beyond physical determinism. *The philosophical cosmology of Popper is a theory of a universe which includes man as researcher, thinker, and creator of science*. Since the problem of freedom goes beyond cosmology, Popper's cosmology gradually turns into metaphysics.

In fact, inclusion of World 3 in the physical universe leads to metaphysical problems. World 3 contains in itself a "world of meanings." That last phrase is an intellectual abbreviation containing such dissimilar things as, for example, various kinds of rules (grammatical rules, rules of good conduct, logical rules and the rules of chess), as well as various kinds of scientific and non-scientific publications and everything that has an influence on our sense of justice and magnanimity, our sense of art, our feeling of beauty, etc. Meanings are pure abstractions, something immaterial. But meanings, through our activity, can influence, and really do influence, the material world. They initiate certain causal chains (e.g., a kicked stone causes an avalanche . . .) and they change those causal chains which are already occurring in nature.

An important question arises: in what way can something immaterial, something deprived of tangible, concrete existence have an influence on the physical world? That is still a question without an answer, but it belongs to that class of questions which, by their very asking, provide certain information. To be specific, that question tells us that the methods of physics are not rich enough to solve all the problems which the universe puts to man. The physical universe, with its closed world of meanings, is an open system.[22]

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[21] Popper used various arguments against "the determinism of Laplace," which ascribes stability (the possibility of unambiguous predictions of future behavior) to the planetary system, not knowing that the problem had already been definitively resolved in the Kolmogorov-Arnold-Moser theorem; see, for example. Appendix 8: "Theory of perturbations of conditionally periodic motion and Kolmogorov's theorem" in V. I. Arnold, *Mathematical Methods of Classical Mechanics* (New York: Springer, 1978), 399–415.

[22] Cf. Karl R. Popper, "Of Clouds and Clocks," in *Objective Knowledge*, 206–255.

6 The Metaphysics of Probabilities

Popper was interested in the concept of probability even in the earlier period of his work. He needed that concept both for methodological problems (the acceptance of scientific theses with a certain degree of probability) and for the interpretive problems of quantum mechanics. He came to the conclusion that the then generally accepted interpretation of probability given by Richard von Mises (the so-called *frequentist interpretation*) is insufficient for those purposes and he supplemented it with his own interpretation, which he called the *propensity interpretation*. In Popper's opinion, at the purely descriptive level, von Mises' frequentist interpretation remains in force for large collections of individuals (statistical masses); however, at the *ontological level*, one must accept *objective propensities* to one behavior rather than to another, the measure of which is their mathematical probability (interpreted frequentistically). Those propensities already occur at the level of individuals (and so without the necessity of considering statistical masses).

The only alternative to the interpretation proposed, according to Popper, would be the *subjective interpretation of probability*, according to which probability would be the consequence of our ignorance about the behavior of individuals. However, his general philosophical position does not allow Popper to admit that subjective ignorance could be the cause of objective knowledge.

With time, Popper began to ascribe to his interpretation of probability even greater meaning. The assumption that everything in the universe is reduced to propensities became an important hypothesis in Popper's philosophical cosmology. The openness of the universe has its basis in the fact that every event which occurs in it is a manifestation of some objective propensity and is at the same time something basically new in relation to past history. The world is a propensity to newer and newer propensities. Emergence (the appearance of the new) finds a place in the very metaphysics of change. In that very way—Popper maintains—it is possible to guarantee indeterminism in the universe without falling into the trap of chaos.

Popper maintained that his understanding of probability could turn out to be fruitful in the interpretation of quantum mechanics (the wave-particle dualism could be "explained" by assuming that elementary particles are propensities), as well as in the justification of realism as a presupposition of physical theory (propensities are *real* properties of the world).[23] What is more, he hoped that his "metaphysics of motion" as a manifestation of objective propensities would provide a new "research program" leading in the direction of the unification of physics in a completely new sense. Those hopes have not yet been realized. Everyone who closely follows the

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[23] See K. R. Popper, *Quantum Theory and the Schism in Physics*, ed. W. W. Bartley III (Totowa: Rowman and Littlefield, 1982); that book constitutes the third part of *The Postscript to the Logic of Scientific Discovery*.

most recent advances in theoretical physics (in the area of so-called unification theories), can see how far scientific progress precedes and, not seldom, surprises, the boldest expectations of philosophers.

7 The Strategy of Evolution

The Popperian understanding of the open world creates a natural place for biological evolution. Popper thinks that the fact of evolution, including the origin of life and of consciousness, can be explained by recognizing the operation of *two factors* in the universe: *relatively stable* structures and *random motions* "superimposed on them." The structures create a hierarchy (structures, structures of structures, etc.); however, the elements creating those structures at all levels move randomly, in the Popperian understanding of randomness, i.e., in the sense of a propensity towards certain directions of change. It is quantum effects that are largely responsible for random motion of that kind. That dualistic schema (structure, random motion) often takes the form of a controlled system and a system of control. But a system of control is flexible, i.e., it operates on the principle of trial and error, and not on the basis of a program written in advance. What is more, we here have to do with a whole hierarchy of control systems. At a higher level, a control system becomes a system controlled by other control systems.

Properties of that kind are characteristic not only of living systems, but are encountered also in inanimate nature. But the entire evolution of the universe is also possible thanks to "real propensities" that are present at all stages of its development. However, life is characterized by certain traits to a greater degree that is the rest of nature. Popper, in agreement with tradition, considers such traits to include: the ability to reproduce, to regenerate, to mutate and the like; he adds to that list one important trait, namely, *the ability of living organisms to solve problems*. That is the best diagnostic trait for life. Life solves problems by the method of elimination of errors (e.g., by the struggle for survival), i.e., by the method of "falsification" of erroneous solutions. In that sense, the development of sciences is to some extent a continuation of that same evolution.

In passing, Popper gives a methodological analysis of *the theory of Darwin*. He shows that that theory *is unfalsifiable* (on the one hand, it says, that the fittest organisms will survive, and on the other hand, fitness is defined only as ability to survive). And so, the theory of Darwin is not a scientific theory, although it contains—as Popper says—certain "scientifically interesting" elements, i.e., it establishes a certain program, which leads to genuinely scientific theories.

Popper's comments on the subject of biological evolution undoubted by contain many valuable methodological observations and ideas which inspire both synthetic ideas and perhaps certain particular lines of research. It is only too bad that Popper, trusting his logico-methodological analysis, too rarely paid attention to the very rich research that has recently been done in the field of the fundamental problems of biology.

8 Concluding Remarks

I do not need to add that, once again, I have limited myself to a selective presentation of Popper's most important views. I have omitted many problems which would have been interesting in an exposition of the place of philosophy in science, but which would be too detailed to discuss in the context of a general course (to such problems belong, among others: the interpretive problems of quantum mechanics and the so-called problem of the arrow of time; both of those problems were addressed by Popper in the spirit of his realism). The book which Popper wrote together with John C. Eccles, *The Self and Its Brain*, in which the authors discuss the philosophical problems of consciousness in light of research on the human brain, would require separate treatment. Popper's thought surely remains incomplete without a sufficiently broad familiarization with his views on the "open society." An open society, i.e., a society which does not see itself as ruled by a deterministically understood history, or which—by the method of trial and error—*rationally* learns to organize its future, is a natural continuation of the evolution which occurs in an open universe (as understood by Popper). Unfortunately, there is no space here for a discussion of those matters. One must only keep in mind, that *The Poverty of Historicism* and *The Open Society and its Enemies* place Popper among the most important philosophers of man and of society (and also of history) of our times.

I think that the thought of Popper also played a crucial role in the history of philosophy in science. In what sense? The entire philosophical tradition of the West, including also the philosophy of nature, always strove for the attainment of subjectively certain knowledge: the ambition to build an "eternal philosophy" is an important factor in the philosophies of the Middle Ages; Descartes' system and all of Kant's thought were perhaps the most typical examples of these tendencies in modern times. That same goal led Whitehead along the intricate paths of his thought, when he tried to deduce the structure of the world from the data of sense awareness understood as comprehensive, still uninterpreted experience. A sharpened critical sense showed Popper the delusiveness of those goals and forced him to go beyond the intellectual ambitions of the individual. Objective knowledge is possible, but it is not the sum of information gained by a "subject," no matter how strong the degree of conviction that supports that information. Objective knowledge cannot be a collection of information established once and for all. The permanence of knowledge is an illusion; conviction about what we know for certain destroys knowledge from the start. There is no authentic knowledge without its openness, without a readiness to make a correction or to learn from previous errors. The fact that it is "knowledge without a cognizing subject," knowledge which is not the property of an individual, but of a collectivity, makes the knowledge objective. That characteristic of objective knowledge is depicted in Popper's metaphor of World 3. Popperian philosophical cosmology should become an inmate of World 3.

Popper himself did much to create a philosophy of nature. To be sure, it is not possible to agree with all Popper's solutions, some of them were overtaken by the development of physics, but the direction taken by Popper must be recognized as creative.

Popperian philosophy of nature, on the one hand, is strongly dependent on the natural sciences themselves; on the other hand, it arose in close contact with philosophy in science, in contact so close that it is sometimes difficult to notice when methodological analyses begin to give results valuable for the philosophy of nature. But Popper's philosophical cosmology is neither a methodology (a philosophy of science) nor is reducible to the sciences themselves. Most briefly, it is possible to say that it *reveals, not seldom thanks to methodological analyses, genuinely philosophical problems that are entangled in scientific problems*. In his many works, Popper tried to show what it is on which the peculiarities that distinguish philosophical problems from scientific ones depend.

The close connection between Popperian philosophical cosmology and the natural sciences, and also the general climate of Popper's thought have led many representatives of the natural sciences who have become familiar with Popper's views to accept them as their own. That is an undoubted opportunity for philosophy in science. Overcoming the gulf between philosophy and the empirical sciences seems to be one of the most difficult, and at the same time one of the most important, tasks that, from the days of Newton and Kant, has faced both scientists and philosophers.

Biographical Notes

Karl Raimund Popper (1902–1994), Austrian philosopher of science, considered to be among the most important thinkers of the twentieth century. He was born in Vienna. In 1918, he began his philosophical studies at the University of Vienna. He finished in 1925. Three years later, he received his doctorate. From 1929 to 1934, he worked as a high school (*Gymnasium*) physics teacher. In 1937, he emigrated to New Zealand where he got a position as lecturer in philosophy at the University of Canterbury. After 10 years, he left for England and he took a specially created chair of critical rationalism at the London School of Economics. Popper's main works in the philosophy of science are: *The Logic of Scientific Discovery* and *Conjectures and Refutations*. He also published works in the field of social and political philosophy: *The Open Society and its Enemies* and *The Poverty of Historicism*.

Appendix: The Influence of Popper's Thought on Contemporary Philosophy of Science

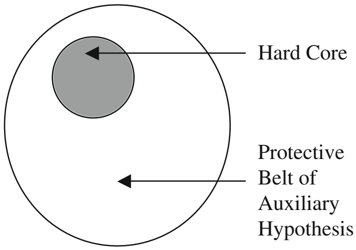
In contemporary philosophy of science the term "rationalism" is almost immediately identified with the views of Karl Raimund Popper. This is not surprising—Popper's rationalism is consistent and is based on rigorous principles and its critical character keeps it free of many of the mistakes of earlier rationalist philosophies. Rejecting the dogmatic rationalism of his predecessors (especially the views of the logical empiricists of the Vienna Circle), Popper became the founder of critical rationalism. Its primary objective is a defense of rationality on the basis of epistemology and an elaboration of the methodology of the sciences which would be subordinated to the laws of logic without falling into contradictions, as had earlier inductionist methodologies. Our aim is not to provide a detailed analysis of Popperian philosophy of science, for there is already a large literature on that topic. It is necessary, however, to turn our attention to the great influence that Popper's thought had on twentieth century philosophy of science. Popper initiated a new trend in epistemological research, in which problems of the development of scientific knowledge took first place. It is possible to say that he was interested not only in the internal logic of knowledge, as was the positivist tradition, but also in "science from the outside," i.e., investigation of the principles which regulate the development of scientific knowledge. *The Logic of Scientific Discovery*, published in 1959, as well as Popper's subsequent books presenting the ideas of critical rationalism, have provoked numerous controversies. It is worth having a look at the ideas to the origin of which Popper's philosophy directly contributed.

Thomas Kuhn's *The Structure of Scientific Revolutions* was written in large part as a reaction to the philosophy of Popper. Kuhn characterized his predecessor as a "permanent revolutionary." He also said that, from the point of view of the history of science, Popper's thesis cannot be accepted. The real development of science shows that it does not develop by the constant proposal of hypotheses and their refutation ("permanent revolutions"), as Popper had said. In Kuhn's opinion, science develops in stages. Scientists accept a certain theory wanting to develop it as much as possible and to get as much as possible out of it. That state continues for a while; Kuhn calls this the period of normal science. One of the essential features of normal science is its institutionalization—publications, instruction in schools and universities, etc. Normal science is conservative and always develops within the framework of a certain paradigm or model which includes, among other things, fundamental theories; criteria of rationality; and metaphysical, epistemological, and methodological assumptions. Transition from one paradigm to another always has the character of a revolution and there is no logical continuity between paradigms. The coming of a revolution is presaged by the appearance of anomalies in normal science—phenomena which normal science cannot explain. After the revolution, the situation stabilizes and a new paradigm is formed. In the history of science—in Kuhn's opinion—it is possible to distinguish four great scientific revolutions:

$$\text{Copernicus} \rightarrow \text{Galileo} \rightarrow \text{Newton} \rightarrow \text{Einstein}$$

Kuhn's philosophy of science is a transition from Popper's absolute rationalism to a situation in which attention is paid to the great influence of extra-scientific factors in science. For those paradigms are often something unconsciously present in the thought of scientists and establish the direction of research. One cannot translate between paradigms; they are incommensurable. Thereby, Kuhn breaks with the postulate of logical continuity in science. Science is not cumulative. Cumulative growth can occur only within the framework of a single paradigm, and agreement between paradigms is impossible, for they are governed by completely different conceptions of science.

Popper's disciples reacted sharply to the criticism of their master and undertook a defense of rationalism in the philosophy of science. One of the defenders was Imre Lakatos. Lakatos' rationalistic program, presented in his "Falsification and the Methodology of Scientific Research Programs,"[24] was not however a mere continuation of Popper's thought. For Lakatos was aware that Popper's "naïve" falsificationism contains many errors. The most fundamental of those errors, is the belief that scientists reject falsified theories. Lakatos, relying on research in the history of science, showed that in reality scientists try to improve falsified theories and do not reject them until they have found a better one. Lakatos called such falsificationism "sophisticated falsificationism." His description of the development of science is also interesting. Science develops thanks to a sequence of theories, and that sequence is what he calls a research program. In such an approach, one can see a clear return to the idea of cumulativism in science (in contrast to Kuhn). The structure of a research program can be presented as follows:



The *hard core*, by methodological decision, is not subject to falsification. Here are found the fundamental claims of a given theory, and they cannot be changed. To the hard core also belong fundamental philosophical, metaphysical, and methodological assumptions (as in paradigms according to Kuhn) and the so-called positive and negative heuristics. The negative heuristic tells us what is not subject to falsification and the positive one—how to build auxiliary hypotheses and how to modify theories. A protective belt of auxiliary hypotheses is built in accordance with the positive heuristic and it can be changed.

In the twentieth-century philosophy of science, a controversy flared up between rationalism and trends which are—not always correctly—called irrationalistic. Critics of rationalism emphasized that there is no absolute criterion of rationality and science is not a purely logical construct, immune from all external influences. Of course it is hard to take seriously the extreme relativism postulated by, among others, the representatives of the Edinburgh school (David Bloor, Barry Barnes, Steven Shapin), who interpreted even the concept of truth by appeal to psychological and social causes. It is not, however, possible to disregard completely what

[24] In Imre Lakatos and Alan Musgrave, eds., *Criticism and the Growth of Knowledge* (Cambridge: Cambridge University Press, 1970), 91–196.

was done in the philosophy of science after Popper. It is important to remember at least Popper's student—Paul Feyerabend. Almost everywhere in his philosophy of science, one can find critical remarks about Popper. As one of the most important, but at the same time one of the most controversial, of Feyerabend's achievements, one can cite the fact that, in arguing with the Popper's logic of the development of science, he started a debate about the principles of the development of science. He put questions not only about the internal structure of science, but most of all about the social, economic, religious, and other factors which influenced science from the outside. He opposed what has been called internalism (of which Popper was a proponent), i.e., the requirement that science be cleansed of all extra-scientific influences, and subscribed to the externalist school. Externalists accept the occurrence of a close, irreducible connection between the content of science and its external determinants.

Chapter 12
Science as Philosophy

1 From Science to Philosophy

We saw in the preceding chapters that from the time of Newton there has been a slow but systematically growing process of the penetration of the natural sciences into philosophy. At first, the process applied only to physics. Its appearance on the scientific scene of modern times was a fact so important that other fields of thought had to react to it. Later, the significance of other sciences, particularly biology, began to grow. Before long almost everyone who considered himself to be a philosopher felt the necessity of saying something either about the natural sciences directly or at least about the problems about which the natural sciences also spoke. For many of them, the achievements of the sciences became either an inspiration for their own reflections or a point of departure from which to elaborate philosophical generalizations.

Philosophical ideas also began gradually to grow around the sciences themselves. At first, these were rather casual thoughts and considerations written by scientists as marginal notes, so to speak, in their scientific works. Gradually, those marginal notes grew to the dimensions of much more organized works. In that way a new philosophical discipline slowly began to emerge—the philosophy of science. But the class of professional philosophers of science (i.e., those who did not themselves do creative work in any of the sciences) emerged only in the twentieth century. This happened primarily thanks to the neopositivists, who reduced all of philosophy to the philosophy of science and—one must admit—quickly raised that branch of philosophy to a high level. In this chapter, I want to turn attention to yet another function which the sciences fulfill in relation to philosophy. That function is often unnoticed but I think that it has risen to be one of the most important elements directing the development of philosophy, beginning at least from the first half of the twentieth century. This is that the sciences them have become a "philosophical fact." Their results, as well as the methods, by means of which those results were achieved, bring with themselves information which philosophy in the long run cannot ignore. If particular philosophers, and particular schools of philosophy, ignore that information, then sooner or later someone else will turn up who will carry out a "philosophical processing" of that information. More and more often, it is not a professional philosopher, but an active scientist who possesses the necessary expertise. Often, he moves relatively clumsily on terrain contiguous to philosophy, but it is easier for a scientist to learn the requisite philosophy than for the philosopher to become knowledgeable about some particular field of science.

What is more, philosophical schools which want to say something about the world but systematically ignore that function of the natural sciences are condemned to marginalization. We saw in Chap. 9 that Romantic philosophy of nature met that fate at the turn of the nineteenth century. In the future, that mechanism of marginalization may operate even more strongly.

I will call that function of the natural sciences “science as philosophy.” That is a name and nothing more. The theme has not yet received a thorough analysis and one should not read into the phrase “science as philosophy” more than was intended. In what follows, wanting only to sketch out the issue which the phrase names, I will briefly present: (a) mechanism and its fall; (b) the philosophical problems of the theory of relativity; (c) the philosophical problems of quantum mechanics; and (d) the contemporary search for a unification theory. Those are three episodes from the history of physics and one story that is still not complete. I think that even just a sketch (because nothing more can be expected in a single chapter) of those topics allows one to work out for oneself an opinion about what should be understood by science as a kind of philosophy.

All four of the topics selected concern physics. That does not mean, however, that other sciences which are traditionally called natural do not also play a similar philosophical role. On this view, the biological sciences, as well as the neurocognitive sciences, are taking on an ever greater significance. The reason they are not considered in this chapter is the author’s lack of competence in these areas.

And one more remark: speaking precisely, mathematics is a formal science and does not belong to the family of the natural sciences, but it also fulfills an important philosophical function, and that in two ways. First, through its applications in the empirical sciences. What is more, it is just those applications in the empirical sciences which were an important source of its effectiveness, and so—at least indirectly—of their philosophical importance. Second, there has also occurred in what is called pure mathematics (i.e., mathematics not concerned with applications) a major revolution (at the so-called foundations of mathematics) the philosophical significance of which we are only now beginning to understand more fully. It is unfortunate that we will have to omit that topic from this chapter as well.

2 Mechanism and Its Fall

Descartes is recognized as the godfather of mechanism. His world was a world of friction and impact (see Chap. 5), which were generally considered to be the properties of mechanical devices. But Newton deserves to be regarded as the real father of mechanism. It is from him that we get that branch of classical physics that is called mechanics, and the frankly unprecedented successes of that branch of physics imposed on many generations of physicists and ordinary people the conviction that the world is a great mechanism. What is more, Newtonian mechanics also imposed on people a particular understanding of what a mechanism is. Descartes would have seen Newton's world as extremely unmechanical since invisible forces operated in it, and, even worse, operated at a distance. At first, Newton was read in exactly that way—as the promoter of a non-mechanical view of the world. But Newton's equations, along with its forces acting at a distance, described so well the mechanical phenomena known from daily life (the fall of bodies, the rolling and collision of balls, the motions of solid bodies and of fluids, etc.) that it quickly became a synonym for mechanics. Adapting a familiar statement of Tertullian, one can say that "the world did not even notice that it had become mechanistic." It soon became clear to scientists that all bodies in the universe attract one another by a force proportional to product of their masses and inversely proportional to the square of the distance between them. It was somewhat less obvious—but accepted as a well-founded hypothesis—that matter is made up of mechanical atoms, invisible to the naked eye, for which the conception of "central forces," i.e., something analogical to Newton's laws of inverse squares, is important.

Mechanism (also called the mechanical philosophy) grew slowly, but unrelentingly. Not counting the rather desperate reaction of Romantic philosophy, it became universal. It was simply not possible to see the world in any other way. In that sense, it was not one of many philosophies of nature, it was the only philosophy of nature. Very often, it was a philosophy which did not recognize itself to be a philosophy. But it is necessary to remember that convictions which one is not very aware that one possesses, are among the deepest and most ingrained.

There is a generally difference between:

Ontological mechanism: The universe *is* one great mechanism; the interactions between its parts have a mechanical character.

Epistemological mechanism: All physical theories, and later all scientific theories, should be reduced to mechanics.

Methodological mechanism: The method of classical mechanics is the universal scientific method.

Those distinctions are a bit oversimplified. They introduce a certain conceptual neatness, but in reality they occur together, creating a certain general, sometimes not very orderly, worldview. Some thinkers also developed a mechanistic anthropology (LaMettrie), a mechanistic sociology (Comte), or a mechanistic ethics (Mill), but without general acceptance.

In the face of such general acceptance, mechanism could not be a very homogeneous worldview. And it was not. Surrounding a certain "hard core" grew various views, of varying degrees of permanence. They varied (sometimes significantly) from author to author, and also evolved with time.

It is understandable that a tendency to extend certain properties of mechanical systems beyond their immediate domain of application prevailed in such an atmosphere. One such property is determinism. If we know the state of a system at a given moment, the laws of mechanics allow us to calculate the state of that system at any other time. Since the universe is a mechanical system, nothing prevents one from accepting the idea that an exact determinism prevails in it as well. The whole history of the universe is established once and for all by its initial conditions. So, determinism became a philosophical doctrine for which no alternative could be seen. From there, it was only a step to the extension of determinism to the actions both of individual human beings and to human societies.

Mechanistic views were often combined with other fashionable philosophical views, especially with positivism and with materialism. Positivism denied value to anything that is not empirical knowledge, and mechanism seemed to be well-grounded in experience. Positivism, speaking precisely, is opposed to materialism (for the latter does not come from experience), but if one realizes that experience can concern only material things, then the difference between them is blurred. It was in particular in the views of the broader circles of the intelligentsia of that time that positivism and materialism supported one another.

Mechanism grew stronger in the nineteenth century as a consequence of the successes of classical physics. The work of physicists like Sadi Carnot, J. J. Thomson, Ludwig Boltzmann, and J. Willard Gibbs led to the emergence of thermodynamics and, shortly thereafter, of statistical mechanics. The science of heat—thermodynamics—became, in the full sense of the term, a branch of modern physics from the moment when it was realized that heat was connected with the kinetic energy of a great number of particles. The number of these particles is usually too great to allow application of the laws of Newton's mechanics, but it is possible to make such an application after taking appropriate averages. In that way, thermodynamics was reduced to statistical mechanics. That was recognized to be an obvious confirmation of the requirement that all the theories of physics be reduced to mechanics.

That success, however, was not repeated, When James Clarke Maxwell discovered the mathematically very elegant the theory of electromagnetism (now called Maxwell's electrodynamics), he himself did not doubt that soon it too would be reduced to mechanics. After all, electromagnetic waves must be propagated in some kind of medium (called the cosmic ether) and the propagation of waves in a medium is a mechanical phenomenon. But there the problems began. The laws of optics (the propagation of light) and of electrodynamics did not want to cooperate with the laws of mechanics. What is more, a series of experiments were carried out, the results of which did not agree with the mechanical interpretation of Maxwell's Laws. Physics was facing a crisis.

Yet one more problem appeared. The spectrum of a black-body (the dependence of energy on wave-length at various temperatures) was determined empirically. Nineteenth-century laws of mechanics and of radiation were not able to explain the shape of the resultant spectrum. Mechanistic interpretations were then so closely tied to physics that this was recognized to be a crisis in physics and not in mechanistic philosophy. Before long, however, it was necessary to think about re-evaluations in philosophy as well. Wilhelm Ostwald advanced the suggestion that the "raw material" of the world is not matter (understood mechanistically) but energy (*energeticism*) and Wilhelm Wien went further and announced that it is not Newton's mechanics that is the fundamental branch of physics, but Maxwell's electrodynamics (*the electromagnetic worldview*). Those conceptions, however, did not survive a single generation. The decline of mechanism was irreversible. It arrived together with the new century.

It was exactly in the year 1900 that Max Planck introduced into physics the concept of a quantum of energy, by which he solved the problem of black-body radiation. In 1905, Albert Einstein created the special theory of relativity (the physical theory of time and space without gravity) and 10 years later, the general theory of relativity (the theory of gravitation). The process of constructing a quantum mechanics, begun by Planck in 1900, ended in the 1920's as a result of the fundamental work of Erwin Schrödinger, Werner Heisenberg, and Paul Dirac. There could no longer be the least doubt that it was not classical mechanics that governs the world, but two new mechanics: relativistic mechanics (i.e., based on the theory of relativity) and quantum mechanics. The first governs the world on a cosmic scale and bodies moving with a speed comparable to the speed of light; the other rules the microworld. And with that the mechanistic paradigm collapsed. And in a way that was irreversible. That process was painful and did not occur immediately. The mechanistic philosophy had ruled in the world of science too long to give up without a fight. To this day, vestiges of the mechanical worldview linger in the convictions of many people, sometimes in overt form and sometimes in dress borrowed from newer ideas. But nevertheless the departure of the mechanical philosophy was final. It would be difficult to find in the history of human thought another view which lasted so long and departed so definitively in such a short period of time.

It is understandable that such a deep transformation would have to lead to a conceptual upheaval. New theories, which, in the creation of the new worldview, took the place of classical physics, were not only confirmed experimentally, but also—growing out of crises prevailing at the foundations of physics—themselves established conceptual standards.

3 Philosophical Problems of the Theory of Relativity

In 1905, Albert Einstein created the special theory of relativity, almost in ready form, although that does not mean that the theory did not subsequently undergo rich development. For, like an embryo, it contained new ideas and applications. Shortly thereafter, Hermann Minkowski gave Einstein's theory an elegant geometrical form. That fact led to geometry becoming one of the most powerful tools of twentieth-century physics. The special theory of relativity resolved the inconsistency between classical dynamics and electrodynamics (Einstein's 1905 work bore the title "On the Electrodynamics of Moving Bodies"), not by appeal to any exotic properties of a cosmic ether, but by abandoning the ether and introducing completely new relations among the concepts connected to motion, time, and space.

In 1915 Einstein created the general theory of relativity. It was his own work. It did not grow from any earlier crisis in physics, but was a natural consequence of the special theory of relativity. Because of the deep changes in the understanding of motion, time, and space a new conception of gravity and of the global structure of the universe was needed. The general theory of relativity, along with its applications—cosmology and relativistic astrophysics—belong to the core of contemporary physics.

There is no space here even for a brief presentation of the physical content of those two theories (I refer the interested reader to the many popular-scientific books on this topic); in what follows I discuss—but only selected—philosophical repercussions of Einstein's theories.

3.1 The Theory of Relativity and Kantianism

The very name "theory of relativity" has contributed not a little to the ideological confusion which has arisen around this theory—the theory of relativity, and therefore the relativity of truth, and therefore Kantianism. Indeed from the beginning (and there are echoes of this even today), general opinion has suspected Einstein of Kantian sympathies. The name "theory of relativity" is indeed misleading. One should keep in mind that this theory emphasizes the role of invariant magnitudes (those which do not change when an observer changes to another intertial system). In fact, Einstein originally wanted to call his theory "Invariantentheorie". Had he done so, perhaps many sterile discussions could have been avoided. Let us, however, put this kind of terminological misunderstanding to one side. There were, however, important thinkers who discerned connections with the transcendental philosophy of the Königsberg thinker at the foundations of the theory of relativity. Among philosophers who cite the theory of relativity in defense of Kantianism were Léon Brunschvicg and Ernst Cassirer. Physicists Hermann Weyl and Arthur Stanley Eddington also saw in it elements of Kantianism. But Hans Reichenbach, for example, strongly emphasized the lack of any connection between the theory of relativity and the philosophy of Kant.

Einstein's attitude towards Kant was rather ambiguous. A passage from his well-known book, *The Meaning of Relativity*, is often cited[1]:

> I am convinced that the philosophers have had a harmful effect upon the progress of scientific thinking in removing certain fundamental concepts from the domain of empiricism, where they are under our control, to the intangible heights of the a priori. For even if it should appear that the universe of ideas cannot be deduced from experience by logical means, but is, in a sense, a creation of the human mind, without which no science is possible, nevertheless this universe of ideas is just as little independent of the nature of our experiences as clothes are of the form of the human body. This is particularly true of our concepts of time and space, which physicists have been obliged by the facts to bring down from the Olympus of the a priori in order to adjust them and put them in a serviceable condition.

[1] Albert Einstein, *The Meaning of Relativity*, trans. Edwin Plimpton Adams (Princeton: Princeton University Press, 1950), 2–3.

That this is an argument against Kant's views is beyond doubt. On the other hand, Einstein shared with Kant the view that in constructing a physical theory theoretical presuppositions come first, and then act as important constraints on theorizing.

The views of Einstein himself, although they must be taken into account, do not obviously solve the problem. So how can the question of the relation between the theory of relativity and Kantianism be presented?

In the first of his works, Kant declared himself in favor of a "kinetic relativism," i.e., a view according to which only motion relative to bodies has meaning; later, however, he went over to a position in agreement with the views of Newton: motion relative to absolute space also has meaning. That was, however, a step on the road to his transcendental philosophy. As we recall from Chap. 8, in his "mature period" Kant believed that time and space are not objects of scientific knowledge, but its conditions. They are schemata present in our cognitive apparatus, which establish connections expressing the co-existence of impressions (space) and the sequence of impressions (time). They are the conditions of the possibility of making general judgments. Their reality—as Kant says—is transcendental in relation to experience, but they are—in a certain sense—empirical, because they make experience possible. Time and space are categories of sensible cognition; they do not, however, exist before knowledge as empty boxes which are only later filled with impressions, but rather they appear through experience as its condition.[2]

According to the adherents of "critical idealism," also called neo-Kantianism (e.g., Cassirer), the cognizing subject imprints its own subjective features on each objective datum. As is known, in the special theory of relativity each observer connected with an inertial system of reference divides space-time into "his time" and "his space." In the opinion of neo-Kantians, the division of space-time into space and time is for each observer his "category." Similar considerations can be made with reference to other relativistic "effects," such as the shortening of length and the slowing of clocks in systems moving uniformly and in a straight line relative to the observer.

What should one think about such interpretive endeavors?

- *Above all, it is necessary to distinguish between epistemological relativism and physical relativism*. The first can take various forms, but speaking most generally, it is based on a relativity of truth; truth depends on the cognizing subject, on circumstances of place and time, etc. The second is based on the claim that, some physical magnitudes depend on the choice of the system of reference. For example, in classical mechanics, speed (including the speed of light) is a relative magnitude; nevertheless in the special theory of relativity the speed of

[2]Marie-Antoinette Tonnelat, *Histoire du principe de relativité* (Paris: Flammarion, 1971), 262–264. In this subsection, I rely heavily on Tonnelat's analyses. It is interesting that Kant often referred to Leonhard Euler's *Réflexions sur l'espace et le temps*, in which Euler put himself on the side of the absoluteness of time and space, but saw in them the necessary conditions of the universal bindingness of the laws of nature.

light is absolute (independent of the choice of system of reference), and the measurements of time and space are relative.

- Physical relativism does not corroborate epistemological relativism. The dependence of certain magnitudes on the system of reference is independent of the cognizing subject and is empirically verifiable (and in that sense is an objective feature).
- The observer in the theory of relativity has no subjectivity. It is simply a synonym for a local system of reference equipped with a clock and possibly with other measuring instruments (e.g., a device for registering and emitting light signals).
- One of the primary motives of Kantian philosophy was the desire to prove that Newton's mechanics is the only possible mechanics and Euclidean geometry the only possible geometry, for—in Kant's opinion—they both consist of synthetic a priori propositions. It is possible to think that, in this respect, Einstein's theory falsified Kant's philosophy, for it showed that another mechanics (relativistic mechanics) is possible and that other geometries (non-Euclidean ones) find important applications in modeling the world (in the general theory of relativity and of cosmology). In fact, those geometries at a small scale reduce to Euclidean geometry, but one must not assert that that is a consequence of some kind of subjective necessity, for it is only the result of the acceptance of certain axioms rather than others (today, we also recognize geometries that are not locally Euclidean).

In human cognition, there is most certainly something that can be called the "Kantian element," i.e., a certain dependence of cognition on our cognitive equipment, language, culture, etc. That element also exists in science, which—obviously—carries with it the mark of human creation, but it is precisely in science that, thanks to its use of the mathematico-empirical method, the "Kantian element" is minimalized. In this respect, the theory of relativity is no exception. Seeking in it a confirmation of the thought of the philosopher of Königsberg can only be a misunderstanding.

3.2 The Theory of Relativity and Positivism and Operationalism

Lord Kelvin's comment is well-known[3]:

> I often say that when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind;

Declarations of that kind, often made by physicists, are the expression of a position which philosophers of science call operationalism. Indeed, the role of measurements in scientific theories is crucial. One can imagine a mathematicized

[3]"Electrical Units of Measurement," A Lecture to the Institution of Engineers, 3 May 1883 in *Popular Lectures and Addresses* (London, 1889) v. I, 73.

theory of contemporary physics as a “calculating machine;” the “free parameters” are its input. Measurement provides the numbers for this input. Next, the calculating machine is run in order to get the output numbers, which can then be compared with the results of new measurements. If the numbers that we get from the theory as output agree (within the limits of measurement error) with the numbers that are the results of the measurements, then the theory passes its empirical test.

That is the general schema. Its application in practice requires ingenuity and often a bit of genius. In the course of history, there have been attempts to codify this kind of research practice and to introduce almost mechanically applicable prescriptions. The connections between positivism and twentieth-century science are manifold, although not always completely transparent. As is known, Einstein, in creating the theory of relativity, drew inspiration from the thought of Ernst Mach, although not so much directly from his positivistic program of purifying physics from “metaphysical intrusions,” as from certain of the speculations which grew from that program concerning the relativity of space and motion. Later, Viennese neopositivists appealed to the theory of relativity (especially to the special theory of relativity) in order to use it as an example in the development of their own ideas. For example, they created several axiomatic formulations of the theory of relativity in order to prove the correctness of their thesis, according to which a scientific theory is nothing more than a properly interpreted axiomatic system.

The special theory of relativity, in another respect, was able to fulfill the role of illustration of the methodological theses of the neopositivists. In the original work of 1905, Einstein’s point of departure was the precise formulation of measurement procedures connected to such concepts as: simultaneity, the length of a body at rest, the length of a body in motion, and the time interval at rest and in motion. For it was possible to formulate these procedures as axioms from which one should be able to deduce all the rest of the theory. That would be an argument in favor of the neopositivist claim that the entire physical content of a theory is contained in propositions which report the immediate results of experiments; the rest is only a “theoretical ornamentation.”

Operationalism was initiated by Percy Bridgman in *The Logic of Modern Physics*.[4] That philosophy can be treated as a certain kind of positivism. Lord Kelvin’s intuition, expressed in the passage cited at the beginning of this subsection, became, in Bridgman’s formulation, a philosophical principle. Every measurement is a sequence of operations and it is just those operations that give meaning to physical concepts. They are simply their definitions. There is no meaning beyond “operational meaning.” Only *operational definitions* have the right to exist in physics. It is not surprising that, in the special theory of relativity, the length of a body at rest differs from the length of a body in motion. Those are two different concepts because the sequence of operations leading to the measurement of the length of a body at rest is different from the sequence of operations leading to the measurement of the length of a body in motion.

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[4]New York: Macmillan, 1927.

Bridgman's operationalism contains a sound idea, because measurements in fact play a foundational role in physics. Bridgman himself, however, very quickly extended his sound observation far beyond the field of physics. He maintained, for example, that expressions in everyday language receive their meaning by way of various kinds of linguistic operations which accompany speech. He also said that calculative operations define the truth of mathematical propositions and verifying procedures (operations)—truth itself.

The transition from the special to the general theory of relativity was, for Einstein, not only a creative process full of tensions but also a great philosophical experience. Einstein fully realized that only when the process was complete. When the process was still underway, all his attention was focused on the solution of the problem; philosophical reflection came later. When the general theory of relativity was ready, Einstein—with a certain amazement—noticed how far he had departed from the positivistic methodology of Ernst Mach. The turning point—as he himself later admitted—was his understanding that it is not differences in co-ordinates, and so not that which is measured by clocks and rigid rods, that have physical meaning, but the co-ordinates themselves. For in his theory, the curvature of space-time, which is determined by calculational manipulation of co-ordinates, is connected with something very physical, namely the gravitational field. These are Einstein's personal views; we should distinguish them from the status of space-time in the theory of relativity as it is found in many analyses in the contemporary philosophy of physics.

With time, Einstein formulated his philosophy of science rather clearly. He never presented it in a systematic way, but it can be reconstructed from numerous statements on the topic scattered through his works and short articles. In reflection on his manner of conducting research, Einstein came to the conclusion that—despite the claims of the neopositivists—a physical theory cannot be reduced to a simple set of observation statements ordered only by some kind of logical schema. Of course, the creation of a physical theory begins from contact with experimental data, but it does so in order to extract from them some kind of general principles or presuppositions, However, these principles or presuppositions are not deduced from the experimental data, but are only the impulse to scientific thought. From those principles or presuppositions, the "body of the theory" is deduced. But even here deduction is not reduced to mechanical rules. It often happens that problems which arise "along the way" require that one back up and modify the initial presuppositions. In sum, the theory is the result "of the free creativity of the human mind." Only when it is already finished can the empirical predictions that are deduced from it (this time by pure mathematical deduction) be compared with the results of real experiments.

There are—in Einstein's opinion—two criteria of truth for a scientific theory: the verdict of experiment and the "internal perfection of the theory." That second criterion Einstein understood to be the mathematical elegance of the theory, its logical simplicity, and a transparent connection with other theories of physics. He ascribed to this criterion great significance. It often requires a spark of genius to know which physical theory is "internally perfect" and which is not.

Einstein's philosophical views are so important because his great authority gave him a significant influence on others. One can note, for example, many striking similarities between Popper's philosophy of science and Einstein's methodological convictions. Indeed this is true to such an extent that it is sometimes suggested that in certain questions Popper only named and made slightly more precise certain of Einstein's remarks. For example, what Popper calls the hypothetico-deductive method of modern physics does not differ much from Einstein's views on the nature of a physical theory. I do not, however, want to decide here the historical question, of whether or to what extent Popper borrowed his views from Einstein. There is, however, no doubt, that contemporary philosophy in science bears the explicit mark not only of the views of Einstein himself, but also immediately—if one can put it that way—of the theory of relativity (I have in mind here both the special and the general theories). That theory, thanks to its extraordinarily elegant mathematical structure and to its unusually rich physical content, is a constant subject of analysis for philosophers of science. There is no great risk in saying that if there had been no theory of relativity, contemporary philosophy of science would be something other than what it now is. As is known, relativistic cosmology arose thanks to the general theory of relativity. Its philosophical significance is so peculiar that it requires separate discussion.

3.3 Relativistic Cosmology and Philosophy

Relativistic cosmology began its existence at the margins of science, relatively far-removed from the scientific front of its day. In 1917, when Einstein published his first cosmological model, the general theory of relativity (on which that model was based) was known only to a few specialists. But even a decade or so later, after a whole series of successive solutions (those of Willem de Sitter, Alexander Friedmann, and Georges Lemaître) to Einstein's equations became known and the first observations of remote galaxies (systematized by Edwin Hubble) fairly explicitly favored some of the solutions which presented an expanding universe, the generality of scientists and astronomers treated the new cosmology rather as a kind of science fiction than as a credible scientific hypothesis. That was reasonable, inasmuch as cosmology was still based on too many arbitrary assumptions.

The situation began to change in that respect, and rather radically, only in the mid-1960s. The discovery of microwave background radiation, on the one hand, eliminated the Steady State model of the universe, which in essence turned out to be the consequence of arbitrary assumptions and, on the other hand, provided an observational basis for the reconstruction of the early stages of cosmic evolution. The development of new technologies, in the fields both of astronomy and of radioastronomy, brought a flood of new observational data, which in turn led to the formation, in the 1980s, of the Standard Model of cosmic evolution. Further exploration of the cosmos followed (the Cosmic Background Explorer (COBE) and Wilkinson Microwave Anisotropy Probe (WMAP) satellites, and the Hubble orbital telescope), which not only consolidated the Standard Model, but also posed many new problems which await solution. Those solutions will come only with the development of better observational technology. Today, it is hard to doubt that cosmology belongs to the family of modern experimental sciences.

What is more, the development of the theoretical side of cosmology ties it closely to physics. For example, high-energy physics found a natural field of application in models of the earliest stages of the evolution of the universe. The observational testing of such "combined" models can confirm or refute not only cosmological scenarios, but also various ideas from the field of high-energy physics. Relativistic cosmology has fused to such an extent with contemporary physics that the rejection of cosmology would cause in physics "gaps" which it would be difficult to explain.

For the first time, modern physics received its "cosmological frame." Because science always develops in a broader cultural environment, diverse cosmological hypotheses have been proposed from the very beginning of its existence, but those hypotheses were such extreme extrapolations of scientific theories that it was difficult to recognize them as anything more than mere philosophical speculations; philosophical—because those speculations drew many elements from contemporaneous philosophical systems or ideas. Today, that situation has, to a certain extent, returned: science itself has created its "cosmological frame" (perhaps with only a small extra-scientific content), which is becoming an ever more "obligatory world-picture" for all of contemporary culture, i.e., a world picture that cannot easily be discarded by an educated person. The creation of an "obligatory world-picture" was hitherto the domain of the philosophy of nature, but now it became a function of cosmology understood as a mathematico-empirical science.

That fact brings further consequences in its train. Inquiries into the nature of time and of space had always been treated as elements of a world-picture and belonged to the field of the philosophy of nature. Today, the topics of time and space (or, more generally—space-time) belong directly to theoretical physics and cosmology.

As is known, in the general theory of relativity (and therefore in relativistic cosmology), the spatio-temporal description is invariant, while the resolution of space-time into time and space depends on the choice of a co-ordinate system. In the great majority of cosmological models, there is no set of co-ordinates in which space-time can be resolved into one universal time and certain momentary spaces (a momentary space is the space in any concrete moment of universal time). Meanwhile, everything points to the fact that universal time exists in our universe (cosmology includes a reconstruction of the history of the universe occurring in just such a time). So the question arises: What causes our universe to belong to the particular subset of all the universes in which that is possible? That is an interesting question and one of great philosophical importance.

The traditional question of the philosophy of nature, "Is space finite or infinite?", appears today in the form a question about the geometrical (and topological) structure of space, and thereby becomes a problem within the competence of cosmology. The fact that the geometry of space does not have to be Euclidean creates a significantly greater range of possibilities than was previously suspected. That problem can, however, have its philosophical content. The question about the structure of space can definitely be answered by the help of observation only when space is "closed" (as the surface of a sphere) and so small that we will sometime be able to embrace the whole by observational research. Otherwise, that question will always remain open for philosophical speculation. Although present observations strongly suggest that space is "open," i.e., in principle extending to infinity, one cannot exclude the possibility that, beyond the "horizon" (beyond domain we can observationally control), space-time curvature plays a non-negligible role.

And of course the problem of "the beginning of the universe" is a question that has great philosophical content. In contemporary cosmology, it takes the form of the problem of the initial singularity. If we do not take the quantum effects of gravity into consideration, that singularity is based on the breaking down of the concept of space-time in the earliest phases of the current stage of cosmic evolution. Along with space-time, all of the physics which we know today (which takes place in space-time, but also with space-time) breaks down as well. If the universe existed "before" the singularity, it has forgotten, as it were, all the information about anything that could have existed "before," information which has been erased from contemporary physics. It is known, however, that the quantum effects of gravity cannot be ignored "near" the singularity, but in order to say something about them we would have to have a corresponding theory. We will say something about contemporary attempts to seek a quantum theory of gravitation and its consequences for the problem of the beginning of the universe later in this chapter. It is still not known whether the future quantum theory of gravitation will remove the problem of the singularity from cosmology or whether it will put it in a completely new light.

4 Philosophical Problems of Quantum Mechanics

The assimilation of a new scientific theory requires a certain amount of time. In the case of the special theory of relativity, it took specialists over a decade; in the case of the general theory of relativity and quantum mechanics, it required over a generation. The philosophical digestion of the new theory and its acceptance by the "general culture" take even longer. Quantum mechanics surprised specialists from the very beginning—and philosophers and broader opinion later—by its dissimilarity from all earlier physics (including the theory of relativity). In spite of all expectations, the microworld did not turn out to be a miniature version of the macroworld. The philosophical acceptance of that fact turned out to be a long process.

The issue which first drew the attention of philosophers was the problem of determinism and of the principle of causality. In the context of classical mechanics, a more or less intuitively understood principle of causality seemed to announce just what the principle of classical determinism did. If events are arranged in a chain of cause and effect, then from a knowledge of the present state of a system, one can predict its future (and past) states. And conversely, if events are subject to a deterministic schema of prediction, that means that they form a causal chain. Heisenberg's Indeterminacy Principle, which does not allow us to know the state of quantum systems (e.g., to know simultaneously both the location and the momentum of an elementary particle) with an arbitrary degree of precision, drew the attention of commentators (although, as we now know, the causes of the probabilistic and indeterministic character of quantum mechanics lie within much deeper layers of its mathematical formalism). Awareness of the differentiation of determinism and causality made its way into discussions and controversies only slowly. For causality does not always have to be unambiguous, a given cause bringing about one and the same effect, and never another; it is also possible for causality to be ambiguous, a given cause being able to bring about different effects, with different degrees of probability. The fact that the evolution of quantum systems does not occur haphazardly, but is subject to probabilistic laws tell us that ambiguous causality holds in the world of quanta.

It was then necessary to provide an analysis of the probabilistic character of quantum mechanics. The problem is that it cannot be reduced to the probability calculus well-known from statistical mechanics when a system consists of too many particles to allow one to follow each of the particles individually. Quantum probability requires a new logic in which the difference between the logical "and" and the logical "or" is blurred (the law of the distribution of "and" over "or," which holds in classical logic, loses its importance). All that shows that probabilistic behavior is not only a feature of a great number of particles, but that a single particle also behaves probabilistically.

Quantum probability theory "harmonizes" with quantum indeterminism. The results of future measurements can be predicted only with a certain probability. Those probabilities evolve in time and this evolution is deterministic: knowing the probability distribution at a certain moment, it is possible—using the appropriate quantum mechanical equations (e.g., the Schrödinger equations)—to determine unambiguously what the probability distribution at any other time will be. Before carrying out a measurement, we can only ascribe certain probabilities to the various possible results of that measurement, but making the measurement itself always gives a determinate result—this result, and not any other one. Why the one and not the other? This, contemporary quantum mechanics does not say. This is a constantly discussed, but still open, problem, known as the reduction of the state vector or the collapse of the wave function.

Although attempts to interpret quantum mechanics in such a way as to make its probabilistic character secondary in relation to a more primary "non-probabilistic reality" (e.g., Bohm's interpretation) are constantly appearing, nevertheless it is becoming ever clearer that physical reality, at it deepest level, is simply different from our macroscopic world and that in particular probabilistic laws rule it, but with a probability different from that which we know in classical statistical physics.

Another feature of quantum mechanics which is surprising (from our point of view) is its non-locality. That feature is based on the fact that elementary particles sometimes behave as though they did not exist in space. For example, two photons emitted by the same atom immediately react to a change in the state of their partner caused by a measurement even when separated from one another by arbitrarily great distances. However, the measurement apparatuses exist in space and they cannot send one another information instantaneously. That "discrepancy" between the micro- and macroworlds leads to the various paradoxes which make quantum mechanics difficult to understand.

The mathematical structure of quantum mechanics gives us a "view" into the microworld. The unusual agreement of theoretical predictions with experimental results obtained through knowledge of those structures is a kind of guarantee that that "view" is accurate. However, the "view" of which we are speaking, is not a perceptual view. The only intellectual access to the microworld is access through the intermediacy of the mathematical structure of quantum mechanics, later confirmed by its agreement with the results of experiments. The problem, therefore, remains of understanding the nature of a "reality" about which that mathematical structure says something and to which the experiments which confirm quantum mechanics point. It is just here that the problem of the interpretation of quantum mechanics arises.

Various interpretations of quantum mechanics have been proposed almost from the moment of its creation. Let us enumerate the most popular of them:

The Copenhagen interpretation. This can also be called the instrumentalist interpretation. It takes quantum mechanics at its face value and claims that complete information about a quantum system is contained in the corresponding wave function. The quantum description is essentially probabilistic. The wave function itself represents the observer's knowledge about the system. Questions like "where was the particle before the measurement?" are meaningless since the answers to such questions are not contained in the wave function. Measuring devices are essentially classical objects and we can only know the results of their interference in the quantum world, the quantum world "in itself" being a meaningless concept. This interpretation was formulated by Niels Bohr and Werner Heisenberg in the 1920s and was later very popular among physicists.

A recent generalization of the Copenhagen interpretation is called the consistent histories interpretation. This interpretation formulates the so-called consistency postulate which allows one to assign probabilities to possible histories of a quantum system. On the one hand, quantum histories are claimed to agree with classical intuitions since they are subject to classical probability theory and, on the other hand, they are consistent with the evolution described by the Schrödinger equation. Among the main proponents of this theory are Robert Griffiths, Roland Omnes, and James Hartle.

The many-worlds interpretation. According to this interpretation, the wave function obeys deterministic laws and the act of measurement does not cause a collapse of the wave function. All possible outcomes of a measurement are equally real. In the act of measurement, the history of the universe splits into many branches, and every possible measurement result is implemented in a certain branch. This interpretation was proposed by Hugh Everett in 1957 and later popularized by Bryce DeWitt.

The statistical interpretation, also called the ensemble interpretation. This interpretation claims that the wave function does not apply to individual systems, such as a single particle, but should be regarded as a mathematical entity with the help of which statistical rules are applied to ensembles of quantum particles. When Einsein was finally convinced that quantum mechanics is correct, he was inclined to support this interpretation; its main present supporter is Leslie E. Ballentine.

Despite the fact that the achievements of quantum mechanics are simply staggering—and that both in its theoretical significance and in its technical applications—progress in its interpretation has not been great. No interpretation has yet come to prevail over all others and specialists still cannot agree on the most important matters. That leads to the very general conclusion (which we hinted at above) that the world of quantum mechanics is fundamentally different from the macroscopic world with which we make contact in our daily experience and for which classical physics is still a good theory.

One must not make too much of the problem of the interpretation of quantum mechanics. That was a "hot" topic when—some 20 or 30 years ago—it was possible to expect that quantum mechanics was the definitive (most fundamental) physical theory. It would be hard to defend such a claim today, for quantum mechanics does not consider the effects of gravity. The force of gravitational attraction between elementary particles is so weak that one can do that with a clear conscience. However, at very short distances (of the order of 10^{-33} cm) the force of gravity cannot be left out of consideration. So a theory which combines quantum physics and the physics of gravitation is indispensable. Despite the many attempts to create such a theory, called the quantum theory of gravity, we do not yet know its final version. Let us only enumerate the main current candidates for such a theory: superstring theory with its newer version called M-theory, quantum loop gravity, causal deterministic triangulation, and theories based on quantum groups and noncommutative geometry. One can expect that, when such a theory emerges (shortly, we hope) it will be combined with a deep conceptual revolution which may drastically change the demands that will be put on the interpretation of quantum mechanics. The new, corrected theory of course cannot refute a theory which did a good job of explaining hitherto known experimental results; it can only generalize that theory in a way that makes the old theory a good approximation of the new one. That does not mean, however, that the earlier interpretations must remain in force. A new conceptual environment can demand a thorough reconstruction of the entire earlier interpretive structure.

5 The Philosophical Problems of the Unification of Physics

All earlier revolutions in physics were connected to deep conceptual changes. That remains true both with respect to major revolutions—when conceptual changes embrace large parts of science, and with respect to smaller revolutions—when conceptual transformations have a "local" character. Examples of great revolutions are: the rise of classical physics at the threshold of the modern period and the quantum-relativistic revolution at the beginning of the twentieth century. One has to think, that when at last we find the ultimate unified theory, it will also be a major revolution which will bring with it far-reaching linguistic transformations.

What kind of transformations will those be? It is as difficult to answer this question today as it would have been to foresee the consequences of the major revolutions mentioned above before they had occurred. Indeed we are today in such a different situation that this time not only have we been waiting for a major revolution for a long time, but we already have several major research programs and a number of working models which are preparing us for that revolution. We cannot, however, be certain that the final theory will not surprise us with something completely new, and even if it is found in a continuation of present research, that it will not "at the last moment" reveal some kind of completely new perspectives.

For it is difficult to draw philosophical conclusions now from a theory that does not yet exist. It is possible, however, to risk a few philosophical remarks.

And so, above all, it seems to everyone that the very existence of a theory unifying all of physics will have great philosophical significance. For philosophers have long advanced ideas on the theme of the unity of the world and have seen that unity either in the scientific method, or in the general principles on which science depends, or even in some kind of systemic philosophical premises. When we do have a unified theory, that unity will take a very concrete form—it will not be the result of a "subordinating analysis," but a result of science itself. Of course, one cannot specify the character of that unity a priori; its disclosure will be the task of a unified theory.

Multiplicity is the correlate of unity. Multiplicity is an evident attribute of the physical world: a multiplicity of individuals, a multiplicity of intervals in time and of places in space, and a multiplicity of traits which can be expressed in numbers. That multiplicity—clearly—cannot be eliminated by a theory of unification. Quite the contrary—we can expect a unified theory to show the source of the multiplicity found in the macroscopic world which surrounds us. If the fundamental theory of physics is a unified theory, then it must explain how the multiplicity which we observe emerges from an underlying unity.

Everything points to the fact that time and space are connected with multiplicity. There have long existed strong reasons (the second principle of thermodynamics) to think that the direction of the flow of time has a statistical character and it seems that the occupation of a place in space is a condition for the existence of physical individuals. Nearly all attempts to unify physics lead to the conclusion that the theory being sought will have much to say on the topic of time and space. Perhaps that theory will be an atemporal and non-spatial one, but one that shows the way in which time and space emerge from the fundamental level; perhaps time and space will exist, but in some "configuration" other than the present one (e.g., as one of many dimensions of some geometrical structure). It seems unlikely that time and space (or, more generally—space-time) will survive the unification revolution in their present form. Those hypothetical predictions are not entirely without foundation. Indeed they are suggested—or even more than suggested—by the partial results of various programs aimed at finding a fundamental theory (superstring theory, M-theory, loop theory) and of the working models which follow from them.

The problem of causality is connected with time and space. Causal chains of events are extended in space-time. A change in its status must bring with it far-reaching changes in the understanding of causality. For example, in an atemporal and non-spatial world, causality cannot concern particular events—because events are identified by giving the time and place in which they occur—but it must have a more global character.

It is not necessary to add that profound changes in our understanding of time, space and causality will have a significance going far beyond the sphere of physics itself. Those are categories which penetrate literally all the spheres of philosophy.

It is obvious that when the final unified theory is known, it will be subject to analyses from all sides, including a metascientific one. Above all, it will be necessary to answer the question: On what presuppositions is the theory based? There is no theory without presuppositions. The final theory will share the fate of all physical theories. It would be naïve to think that it will answer all questions.

Above all, why exactly this theory and not any other? There is an attempt to address this problem. The answer would be: Because there is no other. In such a situation, it would be the only possible one, and therefore—in a certain sense—a necessary final theory. Such an answer seems, however, highly doubtful. For there are in meta-mathematics, limitation theorems (of which the best-known is Gödel's theorem) which assert that, even in arithmetic, it is impossible to realize the ideal of a complete and consistent axiomatic system. It is hard to imagine that it would be possible in physics to get around limitations that hold so rigorously in mathematics. For physics is extremely dependent on mathematics.

The next question, which, in the face of the successes of the final theory (and such successes are to be expected) will become even more pressing than at present: why do mathematical structures so successfully model physical reality? That, I think, is the most important question of philosophy in science. And it is one which will ever more insistently demand an answer.

And finally, the most metaphysical question—the question of existence. Even if we do get a mathematical structure in which the answers to all interesting physical questions are contained, it still will not be clear how the systems of equations got the "spark of existence."

Even if, with the emergence of a final theory, the history of physics will—as some think—come to an end, the philosophical questions will remain and will even—one can suppose—find themselves at the center of scientific attention. But will the history of physics really come to an end? I do not think that it will. And that for at least two reasons.

First, the final theory will concern only fundamental physics. The road from fundamental principles to particular physical phenomena is long and there will be no lack of work for physicists, whose task is the clarification of phenomena already known as well as the prediction of phenomena not yet known. What is more, everything points to the fact that the final theory will be a probabilistic theory, just as is contemporary quantum mechanics (although the concept of probability might undergo further evolution). If that is indeed the way things are, then one should not think that all of physics will be contained in the final theory the way a song is contained on a compact disk; in the evolution of the world, there will always be a place for genuine novelty.

Second, predictions of the definitive end of physics have already been made more than once in the history of the science, but the predictions have never come true. It is not impossible (I personally think that it is very likely) that the final theory, when we finally know it, will raise new questions and open new problems. It is true that today we cannot even imagine them, but that is just the reason for the greatness of the adventure called science—it is always open to the future.

Biographical Notes

James Clerk Maxwell (1831–1879), British physicist. He was born in Edinburgh, Scotland. At the age of fifteen, he presented his first scientific work to the Royal Society of Edinburgh—a paper about the method of drawing oval curves. He studied at the Universities of Edinburgh and Cambridge. In the years 1856–1860, he was professor of natural philosophy at Marischal College in Aberdeen and later was professor of natural philosophy and astronomy at King's College, London. In 1871, he took the position of professor of experimental physics at Cambridge. Maxwell is known above all as the creator of classical electrodynamics, which he presented in 1864 in his work *A Dynamical Theory of the Electrical Field*, describing the fundamental laws of electricity and magnetism. He also worked on the kinetic theory of gases and in his work *Illustrations of the Dynamical Theory of Gases*, he gave it a statistical interpretation.

Max Planck (1858–1947), German physicist. He was born in Cologne. He studied at the Universities of Berlin and Munich. At the age of 21, he received his doctorate. At the beginning of his career, he lectured at Universities of Munich and Cologne. In 1889, he was made professor at the University of Berlin. He worked there until 1928, when he retired. At first, he studied electrodynamics, but his main work concerned the problem of the electromagnetic radiation emitted by black-bodies. He introduced the concept of a quantum of radiation into physics. Planck's discovery caused a radical break with classical physics and set a new course for modern physics. Planck received the Nobel Prize in 1918 and his idea was used, among others, by Albert Einstein to explain the photoelectric effect (1905) and by Niels Bohr in his theory of the structure of the atom (1913). Planck's constants (h) is recognized as one of the fundamental physical constants.

Albert Einstein (1879–1955), physicist. He was born in Ulm, Germany. His family moved to Munich and later to Zurich. There he spent his childhood and youth. He began the study of law at the university in Zurich, but gave that subject up in order to study physics and mathematics. At the completion of his studies, he worked at the Swiss patent office in Bern and at the same time wrote his dissertation in physics. In 1905, simultaneously with the defense his doctorate, he published three landmark articles.[5] Their subjects were Brownian motion ("On the Motion of Small Particles

[5] All of the articles mentioned below have been published in Albert Einstein, Roger Penrose, and John Stachel, *Einstein's Miraculous Year: Five Papers That Changed the Face of Physics* (Princeton: Princeton University Press, 2005).

Suspended in Liquids at Rest Required by the Molecular-Kinetic Theory of Heat"), the nature of electromagnetic radiation ("On a Heuristic Point of View Concerning the Production and Transformation of Light"), and the foundations of the special theory of relativity ("On the Electrodynamics of Moving Bodies"). In the same year, Einstein published a short article entitled "Does the Inertia of a Body Depend on Its Energy Content?" in which he gave his famous equation describing the dependence of energy on mass: $E = mc^2$. In the years 1905–1914, Einstein was a professor of physics at universities in Switzerland, Austria, and Germany. Later, until 1936, he was director of the Kaiser Wilhelm Institute. In 1915, he created the general theory of relativity. In 1921, he received the Nobel Prize for his contribution to theoretical physics and his discovery of the laws governing the photoelectric effect. In 1936, he moved to the United States and was a professor at the Institute for Advanced Study in Princeton until his death.

Percy Williams Bridgman (1882–1961), American physicist and philosopher. He was born in Cambridge, Massachusetts. He studied at Harvard University and received his doctorate in 1908. He joined the Harvard faculty in 1908 and taught there until his retirement in 1954. He was a member of the National Academy of Sciences and of the Royal Society of London. He conducted research into phenomena occurring in materials under high pressure, with particular attention to thermodynamic processes. He received the Nobel Prize in 1946. In philosophy, he is known as the creator of the theory of operationalism, which is contained in his book *The Logic of Modern Physics*, published in 1927.

Appendix: The Dream of Unity—A Sketch of the Philosophy of Science of Albert Einstein

We have already spoken about the philosophy of science of Albert Einstein (see Sect. 3.2 above). One must not forget, that Einstein, in addition to being a great physicist has left us many profound philosophical thoughts. Einstein's views on science deserve detailed treatment, if only because many of them are reflected in contemporary philosophy of science.

Science—according to Einstein—is the intellectual activity of man whose goal is the establishment of relations among those phenomena occurring in the world around us which are accessible to the senses. This brief account takes up three important components of Einstein's understanding of science: the subject of science, i.e., man as a rational being; the fundamental epistemological relation which assures man cognitive access to the world; and finally the objectively existing world.

In fact, Einstein himself did not use technical philosophical language. However, the epistemological and the ontological layers stand out clearly in his thought. The central thesis of Einstein's ontology is a conviction about the existence of an objective world independent of the cognizing subject. That conviction cannot be proved in any way, and each scientist must decide for himself whether that conviction will become for him an object of faith. For Einstein, faith (as he called it) in the existence of an objective world was absolutely indispensable for speaking about any process of knowledge.

Einstein ascribed the following features to the objective world:

- Uniformity and harmony, which are expressions of the fact that the world is not chaotic, but is ordered.
- Mathematicity, which means that the world has a certain property thanks to which it can be modeled using relatively simple mathematics. Einstein said that "God is subtle [because investigating the world with the help of mathematics is not an easy task], but not malicious [because it is a task that can be accomplished]."
- A deterministic character, which Einstein identified with causality (his famous statement that "God does not play dice").

Those features were, for Einstein, the ontological premises of his conception of the unity of science.

The point of departure for Einstein's epistemological thought, is the claim that the only source of our knowledge of the world is impressions. In order for these impressions to become material useable for science, however, it is first necessary to choose those which can be expressed in words. That makes them intersubjectively communicable and allows for their objectivization. The set of individual impressions do not, however, give real knowledge about the world and in particular it says nothing about the regularities which govern the world. Here, the use of reason turns out to be necessary. Reason builds concepts which introduce order into the collection of impressions. It is exactly this that is the foundation of the "rationality of the world," i.e., of the fact that the world can be investigated rationally. Einstein wrote:

> The very fact that the totality of our sense experiences is such that by means of thinking . . . it can be put in order, [is a fact] which leaves us in awe, but which we shall never understand.[6]

Concepts evolve in the direction of an ever better understanding of the connections occurring between particular elements of reality. In the course of the evolution of conceptual systems one can observe this regularity: The deeper we understand the structure of reality, the further we are from the sphere of immediate experience. For Einstein, intuition played an unusually important role in the construction of scientific theory. It does not only allow us to establish connections between impressions and concepts; thanks to it the scientist can also discover the fundamental laws of physics.

Einstein saw physics as an exemplar of the natural sciences and therefore he referred philosophical reflections on science to it above all. He was an adherent of the view that all the sciences should approximate physics, since it is precisely the

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[6]"Physics and Reality," trans. Jean Piccard, *The Journal of the Franklin Insitute* 221 (1936), 3: 349–382, here 351.

laws of physics that apply to all spheres of reality. According to Einstein, the natural sciences have two features:

- All the significant achievements of the natural sciences arose by deduction of conclusions from hypotheses and from general principles and by subsequently comparing them to experience. The formulation of hypotheses and of general principles requires, of course, a thorough knowledge of the problems, but it is, in principle, a "free product of the human mind."
- Even positive results of the comparison of theory to experience is not proof of the truth of a theory although one disagreement with experience is sufficient for its refutation.

A good theory is supposed to satisfy one more requirement: according to Einstein, to be characterized by "inner perfection." An essential element of that perfection is simplicity and, since nature is mathematical, the theory which describes it must be as simple as possible with respect to its mathematical structure. In practice, however, it is difficult to recognize such a criterion as a measurable indicator of the value of a scientific theory (it takes the genius of an Einstein to ascertain the "inner perfection" of a theory). So we get only an heuristic criterion for the selection of scientific theories by means of which we can only determine relative simplicity, i.e., we can evaluate which of two available theories has the simpler structure.

The simpler a theory is, the more universal has to be its character. Einstein wanted the theory of every natural process to be deducible from the fundamental laws of nature. He believed in the existence in the world of a level of organization which is the foundation of all natural phenomena.

The great unification of the theories of physics was Einstein's dream as well as the goal which he set for contemporary physics. The development of every sphere of knowledge should move in the direction of greater simplicity, i.e., of the acceptance of a minimum number of logically independent hypotheses, from which all the laws of nature would be deducible. The most general, of course, were supposed to be the laws of physics, and the particular branches of science, as their logical consequences, were supposed to refer to various spheres of reality. Einstein mentioned the following aspects of the unity of science.

- genetic unity, or the conviction that, at the foundations of the heterogeneity of our perceptual experience lies a homogeneous system, so-called pre-scientific thought;
- linguistic unity, or the observation that there is one universal language of science, independent of particular natural languages (e.g., the language of Euclidean geometry);
- logical unity (also called economy of thought), i.e., the creation of a logical foundation containing fundamental concepts and axioms and common to all the sciences;
- a unity manifesting itself in the unification of physical theories in the course of the historical development of physics.

All those aspects of unity are the consequent of the ontological unity of the world. Einstein argued that, since there exists only one objective world, there should also be only one theory that describes it. After the creation of the special and the general theory of relativity, Einstein devoted the rest of his life to the search for such a final theory. His attempts were, however, premature (for he tried to unify the theory of gravitation with that of electromagnetism and we know today that that cannot be done without taking into consideration also the theory of nuclear forces). And even today, despite partial successes, the complete unification of physics remains still the great, unrealized dream of physicists.

Chapter 13
Problems and Methods of the Philosophy of Nature

We have completed out survey of the most important trends in philosophy in science, prompted by an interest that is not only historical.[1] In philosophy, more than in other spheres of knowledge, the present state of research is conditioned by the fact that others have already addressed a given topic. It is no accident that philosophical treatises are overloaded with references to the literature. The main goal of this survey was to "draw lessons from history," and to follow those lines of thought which, even today, in a climate so vigorously regulated by the natural sciences, would have a chance of becoming philosophical ideas about nature. It is time to put our conclusions in order.

1 The Growth of Criticism

Looking over the systems of the philosophy of nature which I have selected in chronological order, at first evaluative glance one can see—if one can put it this way—a battle for precision and critical character and—what is more—an explicit growth of that precision and critical character over the centuries.

The first problems in the philosophy of nature were posed by the Ionian thinkers in a language that was still very vague and imprecise. Plato chose for his philosophy the form of poetry and myth. It is possible that that form was the most appropriate for raising the problem "at the beginning," since it left many "gaps" just where it was not yet possible to speak with suitable precision. But that did not last for very long. Immediately thereafter, Aristotle decided on the use of the dry language of analysis. That for him purely verbal analyses still too often replaced research into things shows only that the struggle for a suitable degree of precision is difficult and full of traps. Descartes was obsessed with method and the unacceptability of anything that is not "clear and distinct." His *more geometrico* was an attempt to transfer precision from mathematics to all other spheres of inquiry.

[1] This chapter, with minor changes, was published as an article "Czy istnieje autentyczna filozofia przyrody?" *Studia Philosophiae Christianae* 23 (1987): 5–20.

Newton, creating the first work of modern physics, provided a model of precision and critical judgment regulated by experiment. Indeed it was quickly understood that that model could not be transferred directly to philosophy, but standards of critical judgment rose even outside of physics. In the work of Kant (and in the titles of his books) the very word "critique" was put on a pedestal and an entire subtle system was constructed in order to put the particular sciences on a firm foundation.

That same effort was made by Popper, although his critique of the sciences did not come from philosophy, but the other way around—it led to it. For Popper, critical judgment based on the achievements of the newest logic and methodology became a foundation for rationalism and a confession of faith in some form of rationality.

However, a disturbing question obtrudes: Whether the growth of critical judgment in the course of the development of the philosophy of nature as outlined above might not be only a "selection effect," an artifact which arose as a result of a "biased" selection of philosophers for inclusion in this book. That is surely the case, at least in part. The case of Romantic philosophy of nature can serve as an explicit warning and even today it would not be difficult to find among philosophers of nature—and even among those who are well-known—those who, in comparison with the thinkers of antiquity, do not provide much evidence of philosophical progress. But, on the other hand, it is a feature of every evolutionary tree that, besides its main trunk, it has side branches, sometimes even branches disturbing the uniform direction of its growth. I am not saying that, for example, Whitehead's system is "more true" than is Leibniz' just because it is more recent, but I do maintain that Whitehead's views harmonize much better with the achievements of twentieth-century science than do Leibniz' views and for that very reason the thought of Whitehead has to be recognized as the product of a more advanced philosophical evolution than the thought of Leibniz. Both Descartes and Popper strove for maximal precision of thought, but Popper had available to him tools of methodological analysis much sharper than any of which Descartes could even dream. And that is precisely why the evolutionary "arrow of time" goes from Descartes to Popper and not the other way.

The very possibility of a "tendentious selection" of philosophers constituting a sequence of ever greater practice of criticism testifies to the existence of a certain kind of progress in philosophy.

That progress is imperceptible when we take as its criterion a vaguely defined "greater approximation to truth," but it becomes more evident when it is evaluated by reference to growth of critical judgment and precision. Precision of statement is directly connected to the sharpening of concepts and the selection of terms suitable for expressing them. Critical judgment relies chiefly on the elaboration of appropriate methods of argumentation and discussion. One cannot object that the development of formal logic, the logic of language, and the philosophy of science (methodology) during the last two centuries—a development that was undoubtedly prepared by the evolution of philosophy which preceded it—contributed greatly to the raising of standards with respect to precision of expression and to critical judgment in argumentation. Currents which ignore those achievements are certainly not found on the line along which flows the main current of the evolution of philosophical thought. Today, "inquiry" or "philosophical reflection" (expressions which describe rather well the activity of past philosophers) is ever more becoming *research* in the technical sense of the term.

2 The Existence of the Philosophy of Nature

It might appear that whatever has a history must, by definition, exist. In the case of the philosophy of nature, leaving the argument at that would be an evasion. For it would be possible even to write a history of nonsense (I fear that that would be a multi-volume work) and the question here is one of the possible existence of the philosophy of nature as a rational (and therefore not nonsensical) intellectual discipline.

There is no problem about the existence of the philosophy of nature before the emergence of the empirical sciences of nature. It existed—history shows that clearly—at least as an inquiry that prepared human thought for the creation of the natural sciences. Pre-Newtonian systems of the philosophy of nature (let us mention Plato, Aristotle, and Descartes) fulfilled the function of "presciences" of nature. Usually they were a methodological mixture of direct (and not infrequently false) observational data, analyses of statements about nature, and inquiries usually based on some kind of metaphysical assumptions. One of the more important preliminary functions which philosophical systems fulfilled in relation to later sciences of nature was the gradual preparation of concepts (such as velocity, acceleration, mass, momentum, etc.[2]) without which it would not be possible to speak about the rise of the sciences or even about the creation of the conditions for the sound planning and conduct of the experiments that would serve as a foundation for such sciences.

The problem of the existence of the philosophy of nature begins with the emergence of the empirical sciences. It is possible to get valuable knowledge about nature in any way other than by using empirical methods? Let us see what we can learn about this from history.

The fact that various metaphysics of nature (e.g., those of Leibniz and of Whitehead) arose and developed parallel to the natural sciences in itself tells us nothing. For it would first be necessary to determine, whether those systems contain any valuable knowledge of nature. That is not obvious a priori. Let us try to systematize certain conclusions that can be drawn from "the lessons of history."

1. Descartes, Leibniz, and to some extent Kant tried to deduce laws of nature from metaphysical assumptions (Kant, for example, deduced from his philosophical system the thesis that the world must be described by the only possible geometry,

[2]See Max Jammer's series of excellent books on the evolution of several of those concepts, among others—*Concepts of Space* (Cambridge: Harvard University Press, 1969), *Concepts of Mass* (Cambridge: Harvard University Press, 1961), *Concepts of Force* (Cambridge: Harvard University Press, 1957).

namely that of Euclid). The results of that—it is necessary to say openly—were deplorable. From the moment when the natural sciences arose *it has never happened that philosophical premises have served as a justification for the claims of those sciences.* Guiding ourselves by the analyses conducted by contemporary philosophy of science, one must exclude philosophy from *the context of scientific justification* and to raise that decision to the rank of a *methodological principle*. One must emphasize that that principle is not the result of any "inner necessity;" its only—but completely sufficient—justification is the unusual success achieved by the sciences from the moment in which they began to guide themselves by that principle.

2. If by the *context of scientific discovery* one understands everything that creates a climate for, inspires, and suggests new scientific theories, then without a doubt philosophy occupies a prominent place in that context. Again, the proof of that is the history of science. What is more, not only are philosophical elements often present in the context of the discovery of various scientific theories, but philosophy undoubtedly created the "context of discovery" for the origin and development of the natural sciences in general. Few today would dare to doubt that, were it not for ancient and medieval philosophy, there would be no modern physics.

   The context of discovery is not only an "external shell" of science, which, after fulfilling of its function of inspiration, completely ceases to count. And it is not even just a case of its sometimes being difficult in practice to draw a sharp distinction between a discovery and its justification. Philosophy and scientific theories act on one another, sometimes even long after the birth of the given theory and philosophical ideas play a "regulatory" or an "inspirational" role in entire research programs long after the death of those whose new ideas they inspired (see, for example, the history of Mach's Principle[3]). What is more, it sometimes happens that physical theories free themselves to some extent from the influence of the philosophical ideas which they—in agreement with the intentions of their creators—were supposed to realize. And so, for example, as we remember, later analyses of classical mechanics reveal that in this theory—despite Newton's own deep convictions—the (philosophical) idea of absolute space does not work (see Sect. 4 in Chap. 6).

   One can even investigate not only the influence of philosophical doctrines on the rise of scientific theories through the private views of their creators, but also to some extent the presence of philosophical ideas in empirical theories.[4]

3. The above-mentioned "presence" of philosophical ideas in scientific theories is something different from *the philosophical interpretation of scientific theories*. The concept of the philosophical interpretation of scientific theories is certainly ambiguous: one can speak of different kinds of interpretations; the differences between them depend mainly on the philosophy in light of which the

[3] See, for example, D. J. Raine and M. Heller, *The Science of Space-Time* (Tucson: Pachart, 1981).

[4] In this context, one can say that the given empirical theory models a certain philosophical doctrine.

interpretation is made. Let us limit ourselves to naming a few examples of such interpretations—the absolutist interpretation of classical mechanics by Newton himself, the dynamic interpretation of mechanics in the spirit of Leibniz, the process interpretation of the theory of relativity promoted by Whitehead, Popper's interpretations of the probabilistic theories of contemporary physics, etc.

4. All conclusions to date speak about certain, sufficiently widely understood connections or dependencies between the natural sciences and philosophy. It is time, however, to return to the fundamental question: *whether it is possible to speak of philosophical theories of nature co-existing with the natural sciences?* Examples of such theories of nature are: Whitehead's ideas and at least some of the ideas of Popper. Those are telling examples and deserve at least brief analyses.

   Whitehead's system is almost entirely a "philosophical cosmology." Popper's thought, especially his later thought, even if it did not amount to a system in the literal sense of the word, contains at least rich philosophico-cosmological emphases. Those are two cosmologies of very different character. Whitehead is a philosophical maximalist: with one intuitive look, he reaches for the boldest syntheses. One can disagree with Whitehead, but from the moment when one understands what he is talking about, his vision enchants with the boldness and scope of his horizons. Popper is analytic: his philosophical conclusions emerge from meticulous distinctions and carefully chosen definitions. One can disagree with Popper as well, but—in order to be justified in doing so–one must go back to the foundations of his intellectual constructions and search for weak points in the particular links in his chain of reasoning.

   Both systems, different as they are from one another, have a certain logical and informational content (see Sect. 3 in Chap. 11) and both allow for discussion or even encourage it. For if one goes beyond the narrow positivistic criteria—and going beyond them is necessary, as the fiasco of positivistic philosophy of science showed—then one must recognize philosophies of the type that Whitehead and Popper proposed to be intellectually valuable at least as partners in critical discussion.

5. I think, however, that not every philosophical theory of nature is deserving of serious treatment. I will formulate here *preliminarily* two *necessary conditions* which a theory of that type must satisfy if critical discussion is to be worth undertaking. They are that: (a) it cannot be a theory which ignores the natural sciences in the field which it concerns; (b) it cannot ignore at least the fundamental methodological rules elaborated by contemporary philosophy of science. Violations of the first condition make the given philosophical conception an anachronism; neglect of the second condition threatens methodological anarchy. Neither of those two conditions are fulfilled by the philosophy of nature proposed by Hegel; nor are they met by a significant number of the ideas belonging to Romantic philosophy of nature. It is therefore not surprising that this type of speculation is now treated by competent philosophers at best as literature expressing emotions of a certain kind and not as cognitively valuable philosophical analyses.

6. The distinction between the *cognitive planes* of the natural sciences and of philosophy is one of the fundamental accomplishments of the philosophy of science. The difference between these planes is found in their language, their set of concepts, their methods, etc., which are different in philosophy and the sciences. The relationship between these two planes is determined above all by the methodological features of the philosophical system under consideration. There are philosophical systems (e.g., some varieties of neo-Thomism) which place themselves on an non-intersecting plane and indeed one that almost does not interact with the plane of the natural sciences. Such theories of nature, placing themselves beyond possibility of discussion, are not worthy of serious consideration.

It is clear, that the establishment of the methodological character of the positions (i.e., of the "planes") from which the discussion is conducted is the precondition of any discussion. At that stage, the use of suitable methodological analyses is indispensable. If it turns out that "the planes do not intersect one another," then it is necessary to search for a "space" in which both "planes" would be immersed and in which a "translation of languages," opening the way to dialogue would be possible. Of course the expressions "plane," "space," "intersection," etc. must be treated as convenient metaphors. The translation of these metaphors into detailed methodological analyses must be completed separately for every philosophical conception of nature.

The above remarks are not aimed at creation of some kind of methodology of the philosophy of nature. They are only an attempt to systematize the conclusions suggested by the study of some of the most important systems of the philosophy of nature.

3 The Rationality of the World

As soon as arguments were cited in favor of the existence of the philosophy of nature, it became necessary to name at least the most important problems, which it would be the task of the philosophy of nature to pose, to consider, and—if possible—to solve. And in this case history can provide us with examples of this kind of problem.

A problem closely connected to the very existence of the philosophy of nature is *the problem of the rationality of nature*. That problem, expanded to the question of the knowability of all reality, has long been known in metaphysics as the problem of the *intelligibilitas entis* (the intelligibility of being). The philosophy of nature came into existence with the posing of the problem of the rationality of nature and that problem keeps it going. If the philosophy of nature is possible, then it is possible to engage in rational reflection about nature. And it is just that that is the basis of the problem of its rationality. The mathematized empirical method is legitimized by its tremendous successes in the investigation of nature. That also testifies to the fact that one must ascribe to nature a certain *rationality of an empirical type*. Most generally, *by the rationality of nature, one must understand that one of its characteristics thanks to which it is susceptible to investigation*. The ascription of that property to nature is a tacit assumption both of the philosophy of nature and of the natural sciences. It makes sense to return to nature with rational questions only when one has reason to expect that it will give rational answers. The Ionian philosophers were the first to turn to nature with such questions and that is why it is from them that the European history of research into nature begins.

And the affirmation of the rationality of nature is not yet all. The problem only begins there. Rationality also must be rationally explained. From that intellectual loop comes the beginning of one of the most important problems of the philosophy of nature and of the philosophy of science.

The first, and most consequential, was the thought of Plato. Nature is rational because it is the shadow of the world of ideas. The distinction between a world of becoming and of perceptible objects (on the one hand) and a world of being which contains Ideas (forms of things) (on the other) plays an essential role here. The problem of the rationality of nature was removed to a higher level (the world of ideas) and rationality on that level is identified with existence. The separation of nature from existence and their placement in two different realms brings this problem out clearly: the justification of rationality must be sought outside of nature. The shadows of things have a derivative existence. A shadow can only exist as the shadow of something. The world of shadows is rational if it is the reflection of another rationality. The rationality of the world of shadows is to the real (i.e., truly existing) rationality of Ideas as the perfection of shape of a wooden or metal sphere is to the perfection of a geometrical sphere. The Platonic solution tells us to look for ultimate explanations in general categories, such as geometry or simply mathematics.

Aristotle was concerned with the same problem, but changed the perspective. Rationality must be sought in the things themselves. Platonic Ideas were united with their shadows and became the substances of things. Aristotle's substantial forms are Plato's Ideas embodied in (first) matter. The source of intelligibility is the nature of things, i.e., the substance. Aristotle's substantialism is a new form of solution for the problem of the rationality of nature. That solution created an ideal of science (essentialist science) the final goal of which was the apprehension of the essence of things by an act of intellectual intuition. Investigation ends, intellectual unease is quieted, when a definition expressing the essence of a thing can be formulated in the simplest possible linguistic expression. Centuries were nourished on that ideal of science.

Descartes' novelty was based on the fact that he transferred the problem from the ontological plane to the methodological. Knowledge is rational when it is unquestionable. Everything is therefore reduced to the discovery of the right method for attaining certainty. The theory of knowledge became the foundation of certainty (*cogito ergo sum*), its strategy–questioning everything that is questionable (methodological doubt), and the function of transmitting certainty from some propositions to others was taken by geometry (*more geometrico*). But for Descartes, geometry became something more. It somehow embodied or—better—took on the character of Aristotelian substance. The identification of the essence of bodies with their extension of space did not yet abandon the essentialist ideal of science, but it already required that that ideal be realized by formal methods.

Both for Descartes and for Leibniz, the conviction that nature was rational led to a *rationalism* maximally understood, i.e., to a faith in the idea that all knowledge about the world is deducible from a few fundamental rational principles. Leibniz' world is basically one great logical system. The axioms of that system must, however, be supplemented by a principle of the choice of the better; so, logic is connected with ethics. God is the great Logician, but a Logician who acts ethically. The world is susceptible to investigation, the cognitive efforts of man can result in success, since—by reliance on the principle of sufficient reason—we are capable of reconstructing fragments of the divine system of the logic of the world.

Despite the fact that Newton himself still firmly adhered to the essentialist tradition of science, he developed an entirely new method of research. In his hands, mathematics was at the same time the language of description, the tool of analysis, and the medium of deduction. As a point of departure, mathematical formulae get their content from experiments whose results are expressed numerically. Mathematical deduction leads to conclusions which can again be compared with the results of experiments.

But already for Newton, that seemingly rather simple mathematical schema is much more complicated. Mathematics does not serve only as a means facilitating logical operations (deduction). The whole structure of mathematical formalism (the whole structure and not only the beginning and the end, where it comes in contact with experience) seems to speak of the structure of the fragment of reality under investigation. The later methodology of the empirical sciences will tell us, in that context, about the construction of *mathematical models* of reality.

In order to build a mathematical model of the physical situation under investigation, one must simplify it—sometimes drastically. Usually, the very mathematical structures suggest a way to do that. Newton used the process of simplification or stylization of nature; it later became an essential—not at all a marginal or accidental—element of empirical knowledge.

For in the method of modern physics, a certain dualism reigned: mathematics and "the reality given in experience." Those are not two independent domains: there is a very specific resonance between them; sometimes we can simply say that *nature is mathematical*. That statement is a tacit presupposition of the empirical sciences, the sciences which make use of the construction of mathematical models, and the fitting of them—with such great success—to experimental situations. Questions arise for which the empirical sciences themselves do not provide an answer: why is nature mathematical? That means: first, why is there in general a correspondence between nature and mathematics structures? and second, why such simple mathematical structures fit nature (i.e., why nature is idealizable to simple situations)? Those are not trivial questions: It is possible to imagine situations which cannot be described by mathematics at all as well as situations which can be described only by such complex mathematical structures that the human mind would be absolutely incapable of grasping them. The problem of the mathematicality of the world is a new version of the problem of the rationality of the world—a version posed by the form of research which is represented by the modern empirical sciences.

The first philosopher to understand this problem (in its new version) clearly (although he expressed it somewhat differently) was Kant. Kant found an answer to the question of the "mathematical rationality" of the world in the structure of human cognition. The mathematical ways of formulating impressions is proper to our cognitive apparatus. The categories of time and space require us to see arithmetically and geometrically. The rationality of the world is reduced to the rationality of human cognition.

Kant can be seen as a precursor of the rather currently fashionable trend of *anthropological interpretation of the rationality of the world*: the rationality of human cognition is supposed, in some way, to project its own rationality onto cognized reality. A position of that kind runs into a whole series of serious problems. Above all, man himself is an evolutionary product of nature and so in order to explain the rationality of human cognition we will in any case finally have to go back to question of the rationality of nature. Besides, even if man in fact projects his rationality onto the world, it would be necessary to assume that the world has a property thanks to which it is possible to project human rationality onto it.[5] Then, one would have to ask for an explanation of that property of the world. And the problem would remain.

Various ways of understanding the rationality of the world

Plato	Nature is the shadow of the world of Ideas (idealism)
Aristotle	Rationality is in the essence of things (essentialism)
Descartes	Rationality manifests itself through clear and distinct rational knowledge (methodological rationalism)
Leibniz	God is the guarantor of the rationality of nature
Newton	The rationality of nature is its mathematicality
Kant	The rationality of the world is the rationality of human cognition

The dramatic development of the natural sciences brings out the question of the rationality of nature particularly sharply. The question of the rationality of the sciences and their development can be considered to be part of the problem of the rationality of the world, although in the contemporary philosophy of the sciences the rationality of the evolution of the sciences is usually treated as a problem of its own.

In contemporary debates about the rationality of science, the main question is: whether the evolution of science is directed by some kind of laws of the "internal

[5] A helpful analogy from geometry: One can distinguish orientable and non-orientable surfaces as well as oriented and non-oriented surfaces; non-orientable surfaces cannot be oriented. Similarly: If the world did not have a property thanks to which man could project rationality onto it, then the process of projection would be impossible.

logic" of development or rather by the laws of psychology and sociology, which are external factors in relation to science itself?[6] Independent of the answer to that question, the tremendous successes of the modern sciences pose ever more vividly the problem of rationality. That problem certainly has two components: the first concerns those properties of nature thanks to which it is subject to the research efforts of man; the second concerns those properties of the human mind thanks to which those research efforts can be crowned with success.

Karl Popper occupies a distinguished place in discussions of the rationality of the evolution of science. It was precisely his views which launched this discussion. The work of Thomas Kuhn, Imre Lakatos, Paul Feyerabend, and others created one of the most important debates in the philosophy of science in recent years. However, Popper's own ideas go beyond that basically methodological debate. Popper's conception of World 3 as an objective reality present in the universe and changing ("opening") it, contains in itself elements which touch great metaphysics. In Popper's formulation, the rationality of science becomes a cosmological problem.

In my view, the problem of the rationality of the world is one of the most important problems (if not the very most important problem) of the contemporary philosophy of nature (just as the problem of the rationality of science is one of the most important problems of the contemporary philosophy of science). That problem can be keenly felt in the subtexts of the empirical sciences themselves (it is sufficient to recall the words of Einstein: "The most incomprehensible fact about the universe is that it is comprehensible") and it is not possible to think about it without close contact with those sciences.

4 The Debate About Substance

Socrates' conception of definition, as something expressing the essence of a concept, created the foundations of European philosophy. The Platonic understanding of concepts as Ideas of things perceptible to the senses gave philosophy its first comprehensive metaphysical system and even today exercises an influence on thought about the world. Aristotle, uniting Ideas (forms) with things, became the author of his own conception of substance, without which later philosophy of nature, in the form which it took, would be completely unthinkable. I am not speaking here directly of Aristotle's understanding of being as a substantial union of first matter and substantial form; I am speaking rather about two "functions" of substance, namely, (a) causing a being to be what it is, or defining its essence; and (b) serving as the substrate of accidents. (As we recall, Aristotle ascribed to substances yet two other "functions"; see Sect. 2 in Chap. 3) The first "function" was analyzed primarily in metaphysics, the second was the object of analyses in the philosophy

[6] In addition to the books cited in Sect. 2 in Chap. 11, see, e.g., J. Życiński, *The Structure of the Metascientific Revolution* (Tucson: Pachart, 1988).

of nature. It is just that "function" of substance to which I now want to give some attention.

The existence of substance (although understood in various ways) as substrates of properties remained unquestionable philosophical truth until modern times. For Descartes, who identified the essence of bodies with their extension, the function of a substance as a substrate was not only maintained but even emphasized: extension is "extended" in space only to serve other properties as a substrate. Newton, in the philosophical layer of his work, maintained that understanding, although he reduced the significance of extension to the rank of other "primary" properties, such as inertia, impenetrability, mobility, and capacity for gravitational interactions.

That kind of understanding of substance led with time to the modern concept of matter. That concept arose from hybridization of the traditional understanding of substance as substrate and the Cartesian characterization of body as extension and therefore something tangible or, more generally, perceptible. And thus one finds in the concept of matter the idea of some kind of "immutable core" which remains itself, despite the changes which occur among the properties which are supported by the core. The conservation of the "immutable core" seems to belong to the "essence of matter." Another trait closely connected with the essence of matter was supposed to be inertia. One of the greatest philosophical paradoxes was the fact that mechanistic materialism tried to deduce precisely from inertia all the active features of matter responsible for the rich array of phenomena in the natural world.

Leibniz' dynamic understanding of substance had only a small influence on the materialism of the eighteenth and nineteenth centuries. It had its echo only in the energeticism of Ostwald and, above all, in the metaphysics of Whitehead, but with one important caution: Leibniz' monads, the centers of metaphysical forces, were replaced in Whitehead by the intersections of networks of relations and the entire being of "metaphysical atoms" (Whitehead's "actual entities") was reduced to the mutual interactions among them. The world of substance became a process. As we recall, Whitehead did battle with the substantialist-materialist tradition of the modern philosophy of nature, seeing in the most recent achievements of physics confirmations of his views.

The departure from substantialism became ever more frequent. It took various forms. And so, for example, *eventism* announced that the "building blocks" of the world are transitory, temporal *events*, whose relatively lasting sets we take to be bodies or processes. The *pangeometrism* promoted by J. A. Wheeler maintained that the only reality is *space-time*, and the whole rich array of physical phenomena can be interpreted as their geometrical distortions. It is characteristic, that both those ontologies drew inspiration from the theory of relativity.

Popper spoke out against any form of essentialist explanation. His *anti-essentialism* meant not so much renunciation of the search for fundamental elements that would explain reality (see, for example, his propensities) as rather a decided rejection of any form of explanation which appealed to the essences of things (e.g., substances).

For Popper, the opposite of *essentialist inquiry* is *factual research*. The empirical sciences are without a doubt the terrain of such research. In the realm of those sciences, the concept of matter as substrate has completely disappeared. It was already eliminated in the physical layer of Newton's work, in which—as a non-operational concept, not corresponding to anything that can be measured—it did not play any role. In classical physics, the concept of matter was completely superseded by operational concepts such as mass, energy, and density. All of physics, classical as well as contemporary, can be conducted without appealing to the concept of matter. If the term "matter" appears (as it often enough does) in physics texts, then it is only out of linguistic carelessness, a carelessness that is—in a certain sense—unavoidable, caused by the necessity of using ordinary language, even in science. The methods of the natural sciences "do not get a hold of" matter or—in other words—that method is neutral on the question of the existence or non-existence of matter.

However, the problem itself seems to be philosophically interesting. It traditionally belongs to the philosophy of nature. The philosopher of nature could ask: Whether matter (substance) exists, but is transparent to the method of the empirical sciences, or simply does not exist? Or more precisely: Whether acceptance of the existence of matter explains anything in the philosophy of nature or whether it is a completely superfluous hypothesis?

5 Other Problems of the Philosophy of Nature

The questions discussed so far belong to the *fundamental problems* of the philosophy of nature. The method of settling the question about the existence of the philosophy of nature, as well as the problem of the rationality of the world and the problem of substance, determine the entire philosophical or even metaphysical perspective of a system. But besides those central problems, there also exist derivative problems. Their solution, or even the very posing of them, depends essentially on the solution of one or another of the fundamental problems. Of course it will not be possible to analyze here the entire range of the derivative problems that have been posed in the course of the philosophy of nature (besides, I do not pretend to completeness even in the listing of the fundamental problems). I will limit myself to naming some of the most frequently discussed.

Above all, there are the questions connected with space and time. These are derivative problems, but particularly important ones. For Descartes though, the problems of space could be counted among the fundamental problems, since he treated *spatial* extension as the *essence* of material bodies. In Whitehead's system time seems to play a fundamental role because it is precisely time that determines the processuality (or the transitoriness) of the world. The particularly great significance of space and time in various systems of the philosophy of nature comes from the fact that both time and space (in the more recent formulations, space-time) are the "irremovable arena" on which the entire drama of nature is played out. Or, put a little bit differently: time and—to a great extent—space impose on human experience conditions which we cannot verify (we cannot go back in time, we cannot be simultaneously in several places in space).

In the philosophical issues of time and space, the following problems are of first importance: (1a) whether time and space exist as forms of our knowledge (Kant); (1b) whether one also has to ascribe to them objective existence, i.e., existence independent of our cognition (Newton); (2a) whether time and space exist independent of the processes and events which fill them (Newton); (2b) whether they are only the set of relations which order processes and events (Leibniz). Besides yes and no answers to those questions, compromise answers are also possible.[7]

As we saw in the example of systems of the philosophy of nature presented in the preceding chapters, frequently discussed problems include: determinism—indeterminism (in its various meanings), causality, the nature of life and of evolution (and not just the evolution of living things), and the general conception of the universe. The set of these problems creates a *philosophical cosmology* (e.g., in Popper). It differs from an *empirical cosmology* (a science at the border of physics and astronomy), among other things, in that its main aim is understanding (and not predicting) and primarily understanding man and his place in the world.

There is also a set of problems which can be called the *metaphysics of nature*. The following problems would belong here: whether nature is a self-existing being (pantheism, materialism) or one dependent in its existence (creationism)? The set of problems concerning the relation of the world to God, problems connected with the presence or absence of values in the world, etc. In the course of its history, the philosophy of nature has been in equal measures debtor to the natural sciences and to metaphysics.

Biographical Notes

Thomas Kuhn (1922–1996), American physicist, philosopher, and historian of science. He was born in Cincinnati, Ohio. In 1949, he received his doctorate in physics from Harvard University in 1949. In 1948–1956 he taught the history of science. After leaving Harvard, he took a position at the University of California at Berkeley, where he became a full professor of the history of science in 1961. In 1964 he moved to Princeton, where he remained until 1979. He then took a position as professor of philosophy and the history of science at the Massachusetts Institute of Technology. In his most famous work, *The Structure of Scientific Revolutions*, which he wrote after completion of his study of theoretical physics, Kuhn drew attention to the role of paradigms in the historical development of science. The work was published as a book only in 1962. *The Structure of Scientific Revolutions* has been translated into sixteen languages.

[7] Examples of compromise answers to questions 2a and 2b will suffice. Einstein's general theory of relativity, which in physics partially realizes Newton's philosophy and partially realizes Leibniz'. See D. J. Raine and M. Heller, *The Science of Space-Time*, Chap. 9.

Imre Lakatos (1922–1974), philosopher and mathematician. He was born in Hungary to a Jewish family as Imre Lipschitz. In 1944, he completed his university studies at the University of Debrecen with a degree in mathematics, physics, and philosophy. In order to avoid Nazi persecution of the Jews, he changed his name to Molnár. After the war, he took the name Lakatos. From 1947, he worked in the Hungarian ministry of education. As a result of a conflict with the Soviet authorities, he found himself in a Stalinist prison, where he spent 3 years. In 1956, Lakatos fled to Vienna, and later to England. He began studies at the University of Cambridge and in 1961 he received his doctorate in philosophy. After his death, his book *Proofs and Refuations: The Logic of Mathematical Discovery* was published.

Paul Karl Feyerabend (1924–1994), He was born in Vienna. At the end of World War II, in which he took part as a German officer, he began his studies at the University of Vienna. He studied theoretical physics, but he was also interested in philosophy and in the history of science. In 1949, he became head of the Kraft Circle, a student philosophical organization under the guidance of Victor Kraft, Feyerabend's dissertation supervisor and a former member of the Vienna Circle. In 1951, Feyerabend received his doctorate in philosophy and decided to go to England and to study under Wittgenstein. However, before he arrived in Cambridge, Wittgenstein died. Feyerabend began to study under Popper at the London School of Economics. In 1955, he received an academic position at the University of Bristol, in England. Later, he lectured for many years at the University of California at Berkeley. His most important works in philosophy and in the history and of science are: *Against Method*, *Science in a Free Society*, and *Farewell to Reason*.

Appendix: Various Conceptions of the Philosophy of Nature

After the emergence of the natural sciences at the turn of the seventeenth century, when the problem of the existence and tasks of the philosophy of nature was born, various conceptions of that philosophy appeared. Below, we list the most important, more or less in order from more minimalistic to more maximalistic:

- Philosophy of nature as consideration of the problems which are not yet mature enough to be scientific problems. Sometimes the philosophy of nature so understood is called "science at its beginning."
- Philosophy of nature as loose speculation at the margins of the natural sciences.
- Philosophy of nature in the work of the so-called philosophizing naturalists. This took various forms: from speculations that could be placed in the earlier conception to more organized analyses concerning various technical problems from the fields of the particular sciences.
- Philosophy of nature as analysis of the language of science.
- Philosophy of nature as the logical analysis of science.
- Philosophy of nature as the methodology of the sciences. (The last three formulations are now included in the field called the philosophy of science.)

- Philosophy of nature as analysis of the presuppositions of scientific theories or the philosophical interpretation of scientific theories.
- Philosophy of nature as a synthesis of the natural sciences. That synthesis can be “from above,” when it is done on the level of the results of the various sciences (from an encyclopedic juxtaposition of results to more ambitious constructions) or “from below,” when it is done on the level of method or the principles of the various sciences.
- Philosophy of nature as a “philosophy in science.” Its aim is to trace in the sciences traditionally philosophical themes and their analysis by means of contemporary logical and methodological tools.
- Philosophy of nature as the metaphysics of nature. Usually, this conception occurs in the framework of concrete metaphysical systems, e.g., Aristotelian-Thomistic metaphysics, Whitehead’s metaphysics of process, etc.