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Plato's Natural Philosophy and Metaphysics

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Plato's position on the knowledge of nature has been the subject of divergent evaluations.[1] Many scholars believe that Plato's influence in this area was disastrous, in that the central hypothesis he defends, that genuine reality is represented by intelligible forms, of which sensible things are mere images, leads more to metaphysics and even to mysticism than to the study of natural phenomena (e.g., Lloyd, 1968, 1991). It may be, however, that Plato's procedure of making mathematics the model of knowledge and describing the stability manifested in the sensible world in mathematical terms, makes him a precursor of modern science (Brisson, 2000).

These two contradictory positions can be explained by the very structure of Plato's thought. In this regard, I would like to develop the following three positions:

1. Plato wants to account for the sensible world, a task that had been attempted before him by those who were interested in nature.
2. Plato was disappointed by the conclusions of his predecessors: for example, Anaxagoras in the *Phaedo*, and Parmenides and Zeno in the *Parmenides*.
3. As a result of this disappointment, Plato inaugurated metaphysics; this led him to go beyond nature, and set forth the hypothesis of the Forms and of the soul, but the goal was still to explain nature.

1. This chapter was already written when I became aware of A. Gregory's (2000) and T. K. Johansen's (2004) books. In both cases, I disagree on the question of "teleology," which I believe constitutes an anachronism. The question of *telos* is explicit in Aristotle, but not in Plato. Plato does talk about the goodness of the demiurge and the beauty of his product at *Ti.* 28–30, and he says that the god made one choice rather than another, because it was better or best (e.g., 75e), or because it served some good purpose (e.g., eyelids 45d). But the demiurge is good because he is a god who is always doing what is best; and his product is beautiful because it is the image of an intelligible model. The demiurge chose to organize the cosmos mathematically – a cosmos whose stability we can grasp – because using mathematics would result in a good and beautiful product, the best that can be done with recalcitrant "necessity," and not because he was driven by an Aristotelian final cause. Those who interpret the *Timaeus* teleologically are right in a way, but since they rely only on teleology they miss what is truly distinctive and important about Plato's explanations: their mathematical component.

Such a procedure entails a two-stage explanation. In the first stage, Plato borrows the explanation of nature from his predecessors, although he thoroughly transforms it by associating the elements with geometrical figures. In the second stage, he goes beyond nature, by bringing in the soul and the Forms.

Going Beyond Nature in Order to Explain it

The term *phusis* (nature), a noun of action, brings together three notions, origin, process, and result – in other words, the growth of a thing in its totality, from its birth until its maturity and death. In their writings, to which the title *Peri phuseōs* was subsequently given, thinkers prior to Plato engaged in inquiry (*historia*) not into the nature of a thing in particular, but into the nature of the totality of things, that is, the universe. For them, the point (at least from an Aristotelian perspective) was to discover the "material principle," from which all things were engendered. In short, prior to Plato, we cannot really speak of "metaphysics," understood as going beyond nature,[2] since none of the attempts to account for nature goes beyond nature.[3]

Yet Plato shows himself to be unsatisfied by these attempts. In the *Phaedo*, he criticizes the position of Anaxagoras, which, in his view, does not go far enough. Socrates, who has just narrated how disappointed he was by reading Anaxagoras' book, and how discouraged he is by the explanations so far proposed of causality in nature – that is, in the domain of sensible things – explains why he is leaning towards the hypothesis of the existence of intelligible realities (*Phd.* 100c–d). In the first part of the *Parmenides*, Socrates responds to the paradoxes encountered by Parmenides and Zeno in their analysis of the sensible world (*Prm.* 127d–e), which are also described in the second part of the dialogue. If we suppose such a structure, the second part of the *Parmenides* is not a random rhapsody of arguments, but a coherent set of deductions following an overall plan. We understand, then, how the series of eight deductions form the conceptual structure of a cosmology that serves as their background. We are not dealing with a cosmological description, as we find in the *Timaeus*, but with an inventory of the suppositions and definitions on which such a description relies. In other words, while the *Timaeus* is presented in narrative form, the *Parmenides* provides the "tool box" required for the construction of a cosmological model.[4]

Convinced that Parmenides' thesis that the world is a unique whole (*Prm.* 127e–128a) is untenable, Socrates, according to Plato, introduces the hypothesis of the existence of the Forms. In fact, for Plato's Socrates, our universe contains an indeterminate number of things, which, although distinct and different from one another,

2. As I have tried to show in Brisson (1999).
3. On pre-Platonic natural philosophy, see in this volume Hussey, THE BEGINNINGS OF SCIENCE AND PHILOSOPHY IN ARCHAIC GREECE, and Curd, PARMENIDES AND AFTER: UNITY AND PLURALITY.
4. On this interpretation of the second part of the Plato's *Parmenides*, see Brisson (2002). For alternative readings of the second part of the *Parmenides* different from mine, but which also see the deductions as following some overall plan, see Sayer (1978) and Gill (1996).

share a considerable number of characteristics. It is the recognition of this community that leads Plato's Socrates to hypothesize the existence of intelligible realities separated from sensible things, in which the sensible things participate. Since the intelligible reality does not change, and is not subject either to generation or to corruption, it exists in itself, i.e., independently of other things; it should therefore be considered not as an effect, but as the cause of its own being. These realities are defined as Forms (*eidē*). The very term suggests a visual metaphor which Plato uses very widely, when he discusses our grasp of the intelligible.

This distinction between true being and sensible reality is formulated with the help of spatial metaphors: in the *Republic*, we read of the "intelligible place" (*Rep.* VI, 509d2; see also 508c2 and VII, 516b–c, 532d1), and in the *Phaedrus* of a place which is located beyond the heavens (*Phdr.* 247c). Yet this separation cannot be complete, simply because the Forms are supposed to exist in order to solve the paradoxes constantly raised by sensible things. Sensible realities receive their names from the intelligible realities. Above all, sensible realities can be known only through the intelligible. Of sensible realities, we can have only opinion; but opinion is situated midway between the absence of knowledge and true knowledge. True knowledge has intelligible reality as its object, and is obtained by recollection, understood as the rediscovery of a knowledge-content that was apprehended when the soul was separated from the body. This rediscovery, which in this world is triggered by the perception of a sensible object corresponding to intelligible reality, culminates in an intuition assimilated to intellectual vision.

Plato, therefore, was the first to suppose the existence of separate realities. Such a separation may correspond to a religious experience. However, the fact that the upper world consists of Forms rather than of gods explains why, whereas the religious phenomenon seems to be universal, the metaphysical approach is so infrequent. The same idea also enables us to understand how metaphysics, even when assimilated to theology, constitutes a radical critique of the traditional representation of the divine. One cannot either address prayers or offer sacrifices to an utterly separate god. Therefore, as the history of the expression seems to imply, it is separation from nature that enables us to define metaphysics. By the same token, metaphysics is quite naturally associated with theology, from which it is nevertheless distinct and whose dissolution it in the long run entails.

However, if we admit that true reality consists of the intelligible forms, it follows that the knowledge of sensible things cannot be considered as a science in the strict sense of the term. Yet to attribute an inferior status to this knowledge is not equivalent to denying its existence. After all, in the majority of his work Plato speaks of sensible things and tries to supply an explanation for them. We are therefore justified in raising the question of Plato's attitude towards the "branches of knowledge" of his time, such as mathematics, medicine, etc.: Was it that of an enlightened amateur, or of a "genuine scientist"?[5]

5. That is, "scientist" in the modern sense of the term. On the development of Greek mathematics and medicine in Plato's time, see Mueller, GREEK MATHEMATICS, and Pellegrin, ANCIENT MEDICINE, in this volume.

Technē, epistēmē and *alēthēs doxa*

Before we try to answer this question, we should consider an important evolution in Plato's approach to the knowledge of sensible things.

Technē

At first, Plato, like Socrates, found a model of access to the sensible in the *technai*. In ancient Greek, the term *technē* designates a very wide variety of skills and competences, which extend from the figurative arts to rhetoric, from medicine and navigation to architecture, and which include the work of blacksmiths, joiners, and cobblers. These skills and practices have always existed in one form or another, and they are characterized by their specialization, since no expert lays claim to knowledge in its totality.

In the first Platonic writings, the mention of *technai* has two primary functions (see Balansard, 2001). It makes possible the preparation of an effective opposition to all kinds of false knowledge, and it proposes models of know-how. Every *technē* implies an activity (*ergon*), which may consist in the production of an object (a flute, for instance, or a boat), or else deal with the use of these objects (music, navigation), or with the care (*therapeia*) of certain natural objects (land, livestock, or human bodies). *Technē* seeks to control the totality of its object – for instance, the human body – but it must be limited to a particular area; it is on this condition that its competence and autonomy are guaranteed. Within the limits of its own domain, *technē* possesses full knowledge of the rational procedures of its intervention, which it can account for publicly, and which it can transmit by teaching. From this point of view, the *technai* display a normative character. In addition, they lay claim to efficacy (*dunamis*) when they intervene in their object. Because they are always a "know-how," the *technai* are able to serve as a model for ethics and for politics.

At this point, two problems arise that call into question the use of *technē* as a model of knowledge. On the one hand, the objects of all *technai* pertain to the sensible world, which, for Plato, is subject to perpetual change, and for this reason cannot be the object of language and thought. Moreover, every *technē* contains in its principle the pursuit of the interests of the person practicing it, which is not the case for a certain number of fields of knowledge, in which interest does not come into consideration at all.

This is why, without completely abandoning the advantages he had derived from the *technai*, Plato, beginning with the *Meno*, turns towards another paradigm: that of mathematics (this is the thesis of Vlastos, 1988). If human beings are to know sensible things and speak about them, sensible things must display a stability that allows that. Yet it is only mathematics, whether pure or applied, that enables human beings to explain and describe this stability.

Pure mathematics, considered as an object of study in itself, enables the soul to tear itself away from the sensible, even if, within the framework of Greek practice, which gives precedence to construction (by ruler and compass) over calculation, the mathematician must construct figures, and even if mathematics is ultimately based on axioms (more or less explicit), which cannot be demonstrated. In other words, the ideal character proper to mathematics allows Plato to make us understand why it is necessary to hypothesize the existence of intelligible forms, of which sensible things are mere images.

Epistēmē

Moreover, in a way that remains mysterious even today, mathematics appears as traces of the intelligible within the sensible, in so far as it manifests the symmetry that ensures genuine stability to the realities perceived by the senses. All human beings can do is to observe and describe this stability, in the framework of such different branches of knowledge as cosmology, astronomy, physics, chemistry, and biology. Such an inventory of the branches of knowledge is anachronistic, for we do not find any constituted branch of knowledge in Plato having as its name one of those we have enumerated (except perhaps astronomy), and therefore, necessarily, we find no system in which these branches of knowledge could take their place. What is more, in ancient Greek, there is no pair of contrasting terms designating on the one hand the exact description of sensible realities, and on the other the intuition of intelligible realities.

This division of reality among models, which constitute true reality, and copies, which contain only a derived reality, entails a strictly parallel distinction on the level of knowledge and of discourse. This is explained at *Timaeus* 29b–c and 51d–e, where the intellect, which has as its object the intelligible forms, is opposed to true opinion, which has for its object sensible things perceived by the senses. This epistemological opposition alternates, moreover, with the following sociological one: "[in true opinion] every human being has a share, we must say, whereas in intellectual intuition [*nous*] it is the gods [who have a share] and, among human beings, only a small class" (*Ti.* 51e). This tiny class of people is obviously the philosophers.

Alēthēs doxa

In short, science (*epistēmē*) deals with true reality, which is the model of every sensible reality of the same type. This true reality is perceived by the intellect (*nous*). The knowledge that results from this process, like the discourse that transmits this knowledge, is certain, and is reserved for philosophers. True opinion (*alēthēs doxa*), by contrast, is concerned with copies of true reality. These derived realities are perceived by sensation (*aisthēsis*), which, through the intermediary of recollection, leads towards the intelligible. The knowledge that results from sensation, however, cannot achieve certainty, for it has only changing images as its objects. The same holds true of the discourse that transmits this knowledge, and which Plato qualifies as a "likely story" (*eikos muthos*) or "likely discourse" (*eikos logos*), simply because this discourse cannot be true in the full sense of the word, since it deals with images, and not with the true reality which is its model.

Mathematics, pure and applied

Even if we cannot give a determinate status to mathematical or geometrical objects as such, they nevertheless each have a Form that corresponds to them – that of Two or of the Circle, for instance. Be that as it may, we must admit the essential role of mathematics since it mediated between the sensible and the intelligible. Mathematics enables the soul to rise up from the sensible to the intelligible, and its action enables the presence of the intelligible within the sensible to be ensured. In Plato – and this is a very important characteristic – mathematics plays a pivotal role in the process of education.

In the *Republic* (II, 372d–IV, 427c), after demonstrating the existence of a warrior class, from whom are selected those who will become the philosophers who will lead the city, Socrates describes to Glaucon the program of education that will be used to train these philosophers. The warriors, some of whom are destined to become philosophers, will first be initiated into pure mathematics,[6] the various branches of which are reviewed.

Arithmetic (VII, 522c–526c) enables us to begin to apprehend something superior to the sensible. Each sensible perception brings with it the sensible perception of its opposite; and the mind cannot become conscious of the unity and plurality latent in diversity until sensation gives it information on the contrary attributes of the same object. Although such consciousness of unity remains rudimentary, this is truly an act of pure intelligence.

Geometry (526c–527c) is just as indispensable for the achievement of higher education, for it enables us to reach results that are abstract, universal, and even, one might say, eternal. Experience shows, moreover, that whereas arithmetic makes the mind more agile, geometry educates it.

Geometry is immediately understood as plane geometry. But we must also consider geometry in three-dimensional space – the geometry of solids, that is to say stereometry (527d–528e) – for that is required for the application of mathematics to astronomy, which is the science of solids in motion.

We then move on to the geometry of bodies in motion, which interests astronomy (529a–530c). The sky can be seen as an immense moving picture. Like geometry, however, astronomy must go beyond phenomena, in order to determine the general principles that account for the motion of solids. It must therefore abandon the contemplation of the heavens, in order to take an interest in the real problems, which are mathematical in nature, by studying abstract theorems.[7]

The theory of music can be elevated not only above disputes between musicians, but also above the limits imposed upon it by the Pythagoreans, who were interested only in the harmonies perceptible to the ear. Those who wish to become philosophers must rise to the universal and abstract contemplation of harmonic ratios themselves, as we can see from the *Timaeus*, where such ratios account for the regularity of the movements of the heavenly bodies which emit no sound; hence the importance of harmonics (530c–531c).

As we have seen, mathematics presents two faces, as inseparable as those of a coin: one is oriented towards the intelligible, which it allows us to reach; and the other is

6. On this subject, see Pritchard (1995).
7. On this subject, see the polemical work edited by J. P. Anton (1981). See also Mueller (1992).

oriented towards the sensible, where it represents the "traces of the intelligible." At this level, mathematics intervenes in every area of knowledge.

Cosmology

In the *Timaeus*, Plato develops a cosmology. He sets forth a simple, yet coherent and rigorous representation of the universe, the properties of which appear as the logically-deduced consequences of a limited set of presuppositions, even if such presuppositions remain implicit and poorly explained in this dialogue. Moreover, the *Timaeus* appears as the first cosmology in which such a description is carried out with the help of mathematics, and not merely with the help of ordinary language. Aristotle, particularly in the *De Caelo* and the *Physics*, never stops criticizing Plato's mathematization of the universe. However – and it is in this respect that the *Timaeus* is anchored in tradition, including myth – Plato's description of the universe remains tied to a description of the origin of man, and even of the origin of society, as is illustrated by the myth of Atlantis, summarized at the beginning of the dialogue and narrated in the *Critias*.

For Plato, a cosmology that aims to set forth a simple representation of the universe must be able to answer these two questions: On what conditions is the sensible world knowable? How can we describe it? These questions are inspired by the following conviction: incessant change cannot be considered to be true reality. In order to become an object of knowledge and discourse, the sensible world must, even in its transformations, display something that does not change, something that is genuinely permanent, and which is therefore identical in every case. Plato responds to this demand by making the following hypothesis, which presents a double aspect: there exists a world of intelligible forms, immutable and universal realities that are the object of true knowledge and discourse, and there is a world of sensible realities, which participate in the forms, of which they are mere copies.[8]

Since resemblance may be defined as identity reduced to certain aspects, sensible things, if they are only images of the intelligible forms, must simultaneously display a certain resemblance to the intelligible forms and be dissimilar to them, lest they be confused with the corresponding intelligible forms. The demiurge guarantees resemblance, whereas *chōra* explains difference. We must hypothesize the existence of *chōra*, in order to explain why sensible things are different from the intelligible forms, in which they nevertheless participate (*Ti.* 52c–d).

Chōra is that which supplies a location for sensible things, which are thereby situated in exteriority, separate from one another. An analysis of the discourse which deals with sensible things enables Plato to show how *chōra* is the stable receptacle in which sensible things appear, and from which, after a certain lapse of time, they disappear (*Ti.* 52b). Moreover, some of Plato's images and metaphors, like the "mother" and the "nursemaid," suggest that *chōra* is in a sense constitutive of sensible things. Sensible things display thus a certain consistency, which explains why they are impenetrable, and so cannot occupy the same place at the same time. In this way *chōra* enables us to explain why sensible things, although they must resemble the intelligible, are different

8. On participation, see Notomi, PLATO'S METAPHYSICS AND DIALECTIC, in this volume.

from it: they are located somewhere, and they are subject to a certain consistency, if we take this term in a very wide and imprecise sense. So *chōra* includes a double aspect, both spatial and constitutive, as we shall see below; and this is why we must resist the temptation to identify *chōra* with a kind of defective matter (*hulē*), as Aristotle did. In itself, *chōra* is bereft of measure and proportion, but as a result of this it can accept all kinds of measures and proportion.

Nevertheless, *chōra* is never described in the *Timaeus* as such and in its pure state. When the demiurge undertakes to introduce measure and proportion into it, it already presents traces of the four elements (*Ti.* 52d–53c), which are agitated by a mechanical movement bereft of order and of measure. Plato calls this principle of resistance *anankē*, a term that is usually translated "necessity," but which should be understood as the set of unavoidable consequences which, in the sensible world, impose severe limits upon every rational intention. By admitting the persistent presence of "necessity" in the universe, with which first the demiurge, and then the world soul must deal, Plato acknowledges that the order presupposed by his cosmological model cannot but remain partial and provisional. We are thus far from Leibnizian optimism. Since order reigns over only a part of the universe, all cosmological explanations are condemned to remain partial and provisional.

In the sensible world, permanence is manifested with the following characteristics: causality, stability, and symmetry. There is causality if every event depends on a cause; stability if the same cause always produces the same effect; and symmetry if this relation of causality remains invariant despite incessant transformations. This invariance, which can be expressed in terms of mathematical ratios, in fact constitutes the essential part of the sensible world that human beings can come to know and describe. Nevertheless, the knowledge and discourse that have sensible things as their object maintain a relation of copy to model with the knowledge and discourse that have intelligible forms as their object. This relation is similar to that of sensible things with regard to intelligible forms. This knowledge and the discourse that expresses it are never true, but remain probable, for they deal only with images, and not with true reality. The demiurge fabricates the universe, which is a living being endowed with a soul and a body, by keeping his eyes fixed on the intelligible.

Astronomy

Why does Plato consider the universe to be a living being – that is, as a being endowed with a soul? In ancient Greece, the main problem in cosmology, as we have seen, is to account for what is orderly in the sensible world although it changes constantly, and above all for the most regular movements observed in it, those of the celestial bodies. In this case, however, how can we explain both the existence of movement and of the order this movement manifests?

It was Newton who, in 1687, formulated the law of gravitation: two bodies exert a force of attraction upon one another proportional to their masses and inversely proportional to the square of their distance. The law of inertia, according to which a body which is not subject to any force can only be at rest or display rectilinear and uniform motion, had to await Galileo to be formulated, and Newton to be extended to celestial bodies. If these laws are not available, one must hypothesize a motion that is not perceived by the senses, but which accounts for the origin and the persistence of the totality of movements in the universe, and especially of the most noble of them, those that animate the celestial bodies. According to Plato, this reality is the same in nature as the principle of spontaneous movement in living beings: it is a soul.

This hypothesis is just as plausible as that of the existence of "movement at a distance." In living beings, which are, by definition, endowed with the principle of spontaneous movement which Plato calls "soul," a certain regularity within change manifests itself: a member of a given species engenders another member of the species, lives a specific number of years, displays certain characteristics, etc. Moreover, the human soul is endowed with an intellect, which ensures it a behavior coherent and in conformity with intentions that are more or less well-defined. An analogous line of reasoning allows us to associate these two domains of facts, and suppose that the sensible world has a soul endowed with reason (*Ti.* 30a–c), as is the case for humans. Since this is so, we can better understand how the demiurge goes about fabricating the body and soul of this living being which includes all living beings – that is, the universe.

The world soul, which ensures the permanence of the mathematical order established by the demiurge within the universe, displays the following characteristics, whenever it comes to exert absolute power (*Ti.* 34c): it is an intermediate reality, which resembles a series of overlapping circles (the most "noble" of plane figures, for it presents the greatest symmetry), which are interrelated mathematically with one another, and which explain all motion in the universe, whether psychic or physical.

This reality intermediate between the sensible and the intelligible represents, within the sensible, the origin of all orderly motion, the circular movements of the heavenly bodies, and the rectilinear movements of sublunary realities. Thus, the *Timaeus* presents the constitution of the world soul as if it were the construction of an armillary sphere, i.e., a globe made up of rings or circles, representing the movement of the heavens and the stars (mentioned at *Ti.* 40d). We must bear this image in mind to comprehend what follows.

By bringing in mathematical relations (geometrical, arithmetical, and harmonic), which are also used in music, at the level of the world soul, Plato is merely trying to account for the two characteristics of permanence and regularity, characteristics that have been observed since earliest antiquity in the heavenly bodies, and that have led human beings to regard them as divine. In order to account for these two characteristics, Plato formulates two postulates: 1) The movements of the heavenly bodies follow a circular trajectory, so that their motion is permanent. 2) These motions obey laws defined by three types of mathematical relations known at the time, so that their movement is regular, despite appearances to the contrary (see Knorr, 1990).

In the *Timaeus* (38c–39e),[9] Plato proposes an astronomical system of astonishing simplicity. Indeed, this astronomical explanation brings only the following two elements into play: the circular movement of the celestial bodies, a hypothesis which was accepted until Kepler (the law of orbits, in 1609), and three types of mathematical relations: geometrical, mathematical, and harmonic. The extraordinary complexity

9. For a table of celestial motions in the *Timaeus*, see Cornford (1937, pp. 136–7).

of the movements which seem to affect the celestial bodies is thus reduced to two elements of mathematical nature: circles and means.

Physics and chemistry

The demiurge adapts this soul to the world's body (*Ti.* 34b, 36d–e), which appears as a gigantic sphere, since, as the copy of a perfect original, this body must have the perfect and symmetrical form. In the geometry of three-dimensional space, no form is more symmetrical than the sphere.

The elements

In conformity with a traditional opinion that probably goes back to Empedocles, and which was to continue down to the eighteenth century, Plato takes for granted that the body of the universe is fabricated exclusively from the four elements: fire, air, water, and earth (*Ti.* 56b–c). Yet he goes much further. On the one hand, he sets forth a mathematical argument, to justify the fact that there must be four elements. Above all, he is conscious of showing a high degree of originality (*Ti.* 53e) by establishing a correspondence between the four elements and the four regular polyhedra – that is, he transposes the whole of physical reality and the changes that affect it into mathematical terms.[10]

These four polyhedra are themselves constructed from two types of surfaces, which themselves result from two types of right-angled triangles.

The mathematical constitution of the elements

The two types of right-angle triangles which play a role in the beginning are the right-angled isosceles triangle, which is half of a square (Figure 12.1b), and the right-angled scalene triangle, which is half of an equilateral triangle of side x (Figure 12.1a).

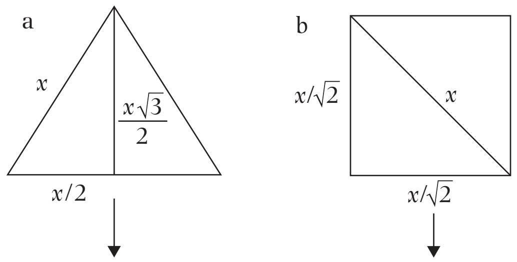

Figure 12.1

10. It should be noted that the construction of the first regular polyhedra is attributed to Theaetetus (415–369 BCE), a contemporary of Socrates, whom Plato depicts in the prologue of the dialogue which bears his name (*Theaetetus*); this indicates that Plato devoted considerable attention to the development of mathematics in his time.

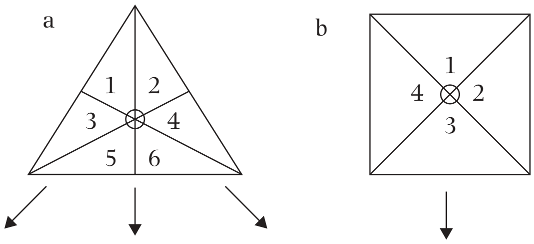

Figure 12.2

These two elementary right-angled triangles enter into the construction of two other types of surface: the square and the equilateral triangle. A square results from the union of four right-angled isosceles triangles (*Ti.* 55b) (Figure 12.2b); and an equilateral triangle is the result of the union of six right-angled scalene triangles *Ti.* 54d–e) (Figure 12.2a). In order to constitute a square, two right-angled isosceles triangles would have sufficed, just as would two right-angled scalene triangles have sufficed to constitute an equilateral triangle. We may suppose, however, that, in the case of the square and of the equilateral triangle, Plato wants to find a center of axial symmetry (cf. Euclid, *Elements*, XII,18, scholium), which would ensure that none of the triangles that make up the square or the equilateral triangle could have preeminence over the others. This may perhaps be an implicit criticism of Pythagoreanism, in which right and left had opposing values.

Equilateral triangles are used to construct three regular polyhedra: the tetrahedron (*Ti.* 54e–55a, 4 equilateral triangles, Figure 12.3a), the octahedron (*Ti.* 55a, eight equilateral triangles, Figure 12.3b), and the icosahedron (*Ti.* 55a–b, 20 equilateral triangles, Figure 12.3c), associated respectively with fire, air, and water. In addition, squares are used to make up the cube (*Ti.* 55b–c, 6 squares, Figure 12.3d), which is associated with earth. Finally, there is a fleeting mention of the dodecahedron, the regular polyhedron that is most similar to the sphere (*Ti.* 55c), the geometrical figure associated with the body of the world (cf. *Ep.* XIII [apocryphal], 363d).

All the properties of the polyhedra associated with the four elements may be gathered together in an easily readable table (see Table 12.1). Two observations result from an attentive reading of Table 12.1:

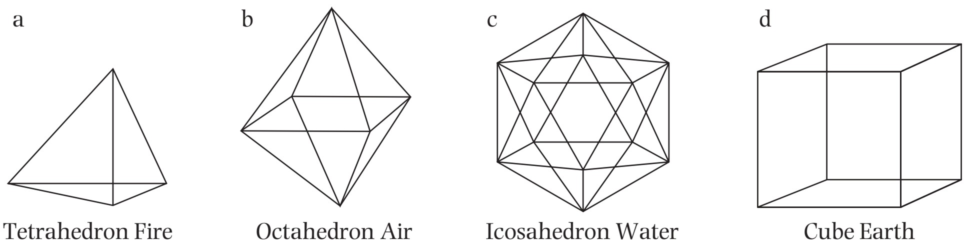

Figure 12.3

Table 12.1

Element	Regular solid	Number of faces	Number of right-angled triangles
fire	tetrahedron	4 equilateral triangles	24 scalenes
air	octahedron	8 equilateral triangles	48 scalenes
water	icosahedron	20 equilateral triangles	120 scalenes
earth	cube	6 squares	24 isosceles

1. The regular polyhedra that correspond to the various elements are described exclusively as a function of the number of faces that make up their envelope; and
2. the edges of these faces are defined on the basis of an original value that corresponds to the length of the hypotenuse of the elementary right-angled triangles that compose them; but this value remains indeterminate (*Ti.* 57c–d). Such indeterminacy has considerable importance, for two reasons: on the one hand, it reduces the explanatory power of the geometrical model proposed by Plato, by going against its simplicity; on the other hand, however, it allows the varieties of one and the same element to be better explained.

Plato wants to show how the cosmological model he proposes, and which can be reduced to four elements, assimilated to regular polyhedra composed of equilateral triangles and squares, themselves made up of regular scalene and isosceles triangles, allows for the description of the objects of the entire sensible world, which are mere varieties of the four elements, or their combination, and even for the description of their properties. At *Ti.* 58c–61c, we find a few examples that will illustrate this point (Table 12.2). The most complex substances found in the universe are, indeed, only varieties of the four elements. The entire material structure of the universe is reducible to the four elements and ultimately to two kinds of equilateral triangles.

The mutual transformation of three of these elements

In order to account for the mutual transformations of these polyhedra – the tetrahedron (associated with fire), the octahedron (associated with air), and the icosahedron (associated with water) – Plato takes into consideration only the number of surfaces which constitute their envelope. The correspondences established between the number

Table 12.2

Element	Polyhedron	Sides	Weight	Mobility	Sharpness
Earth	Cube	6 Squares	Heavier	Stable	Malleable
Water	Icosahedron	20 Triangles	Heavy	Less mobile	Sharp
Air	Octahedron	8 Triangles	Light	Mobile	Sharper
Fire	Tetrahedron	4 Triangles	Lighter	Very mobile	Sharpest

Table 12.3

1 [fire] = 4 Δ
2 [fire] = 2 × 4 Δ = 8 Δ = 1 [air]
1 [fire] + 2 [air] = 4 Δ + 2 × 8 Δ = 20 Δ = 1 [water]
$2^1/_2$ [air] = $2^1/_2$ × 8 Δ = 20 Δ = 1 [water]

of equilateral triangles making up the surface of these polyhedra enable the formulation of the mathematical equivalencies that explain how the elements are transformed into one another, and how generation and corruption in the sensible world occur.

Such an explanation is based upon the following presupposition: the two types of right-angled elementary triangles can neither be created nor destroyed. Consequently, in every transformation, the number of triangles of each species implicated in a transformation is conserved. In addition, only the elements which correspond to polyhedra whose faces are forms of equilateral triangles can be transformed into one another. It follows that water, air, and fire can be transformed into one another. Earth, which corresponds to the cube, whose faces are squares, is affected only by processes of decomposition and recomposition. In short, the transformation of the elements is considered as a function of the surfaces making up the regular polyhedra, and not, as would be natural, as a function of their volumes. The rules of the mutual transformation of fire, air, and water can be summarized in a relatively simple table (Table 12.3). Such a solution is surprising, for it takes into consideration only the surfaces surrounding the polyhedra, even though these polyhedra are volumes.

How can we explain this surprising solution? Three explanations can be advanced:

1. As we can still note in Euclid, what defines a polyhedron is its form, i.e., its limit, which corresponds to the set of its faces.
2. The indeterminacy of the length of the hypotenuse of the elementary right-angled triangles that compose the equilateral triangles makes it difficult to explain the mutual transformation of polyhedra whose faces are not equilateral triangles of the same surface. In other words, only elements of corresponding varieties (whose faces are equilateral triangles of the same dimension) can be transformed into one another.
3. The mathematics known in Plato's time encountered numerous difficulties when it came to extracting square roots, and it was unable to extract cube roots.

The problem of change

The explanations proposed so far do not suffice to account for the mechanical changes that affect the whole of the sensible world, because they lack the following axioms:

1. Everything that is corporeal must be somewhere (*Ti.* 52b).
2. The universe is not uniform, and the motion observed in it originates in the lack of uniformity found within it (*Ti.* 57e). This lack of uniformity can be explained in

two ways. A weak interpretation justifies it by the fact that there exist four regular polyhedra that cannot fit perfectly into one another. A stronger interpretation states that this non-uniformity results from the fact that the length of the hypotenuse of the elementary right-angled triangles remains indeterminate; it follows that the dimensions of the elementary polyhedra that make up all sensible things can be different. This lack of uniformity thus explains the incessant change to which the sensible world is subject, a change the world soul will try to set in order, but only where it can.

3. There is no void in the sensible world (*Ti.* 58a, cf. 79c), or, what amounts to the same thing, everywhere is filled with something, that is something corporeal.
4. The world sphere envelops all that is corporeal. Within this sphere, the four elements are distributed in four concentric layers (*Ti.* 33b, 53a, 48a–b), and between those layers exchanges are explained as follows. Since there is no void, the particles, which have a certain weight, cannot spread to infinity towards the outside, while, on the inside, they can only circulate within the always-filled interstices, originating from the absence of homogeneity among the elements. The result is a chain reaction (*Ti.* 58b; cf. 76c and *Laws* X, 849c), which entails a process (*Ti.* 58b) displaying the two movements that govern all transformations of one body into another, which we have mentioned above: division and condensation, decomposition and recomposition.

We must ultimately imagine the Platonic universe as a vast sphere filled with a homogeneous fluid, bereft of all characteristics – that is, *chōra*. Yet the greatest part of it is enclosed within envelopes that delimit the outer surface of each of the four regular polyhedra: tetrahedron, octahedron, icosahedron, and cube. These elementary components tend to be distributed in four concentric layers; but this tendency runs counter to the movement of rotation that carries along the whole of the sphere. The result of this movement is the displacement of the regular polyhedra, or a modification of nature, with fire becoming air, air becoming water, and *vice versa*. This representation introduces a contradiction: in the Platonic universe, we must consider both the continuity that characterizes *chōra*, and the discontinuity the regular polyhedra inevitably establish. Platonic physics is thus neither atomistic like that of Leucippus and Democritus, nor a physics of continuity, like that of Parmenides, Zeno, and Melissus; it is intermediate between the two.

We must acknowledge that since the mechanical movements of the sensible world are dominated by a soul that displays a particularly rigorous mathematical structure, and since the demiurge has fashioned *chōra* mathematically, introducing the regular polyhedra into it, every transformation of one body into another can be explained in terms of mathematical interactions and correlations. Mathematics allows us to apply to the sensible world certain predicates of the intelligible world in which it participates; the sensible world thus acquires permanence and regularity. Ultimately, it is mathematics that accounts for the participation of the sensible world in the intelligible world. And if the sensible world is indeed an image of the intelligible, it must therefore be constructed mathematically; from this point of view, mathematics fixes the limits of Platonic cosmology. Nevertheless, it remains true that Plato was able to use the most elaborate concepts offered by the mathematics of his time; we must consequently recall that the limits of Plato's cosmology coincide with the limits of the mathematics of his time.

Ultimately, nothing guarantees that the mechanical motion just described will always display enough regularity and order to allow people to think about it, speak of it, and act within it. Therefore, Plato makes the world soul prolong the action of the demiurge; this hypothesis not only explains why and how the motion of the sublunary bodies is orderly, but also how and why it is also constantly subject to mathematical laws, giving it the possibility of displaying a certain regularity and permanence. The more the world soul is ruled by rigorous mathematical laws, the more the motions that affect the sublunary sensible world are likely to be orderly.

Biology

If we define biology as knowledge that deals with living beings, we face a whole series of problems when we take up the question in Plato. For him, a living being is one endowed with a soul, where the soul, as we have already seen, is defined as the self-moving principle of all spontaneous motion, physical as well as psychic. Since they are immortal, all souls present themselves as substitutes for the world soul, the constitution of which is described at *Ti.* 35a–b.

Beings endowed with a soul are nevertheless classed hierarchically. At the summit are the gods and daemons; then come human beings – men and women – and the animals that live in the air, on the earth and in the water; plants are ranked at the bottom. Thus, when we wish to speak of biology, we are forced to make a distinction. We must separate human beings and animals, since they are distinct both from plants, which possess only an appetitive soul, and from the gods (including the world and the celestial bodies) and the daemons, whose body is not subject to corruption. Nevertheless, if, as Plato believes, one and the same soul passes through various animal bodies, then the difference between human beings and beasts is radically attenuated. It is a human soul, displaying the same structure as that of gods and daemons, which animates the bodies of men, women, and even all animals (according to the definition given above) that live and move in the air, on the earth and in the water. As a result, men, women, and all the animals are human beings, originally male, but subject to a process of degeneration as a function of the use they have made of their reason in a previous life.

Human beings are constituted on the same model as the universe (*kosmos*): they possess a soul, whose rational part displays the same two circles that constitute the world soul; these circles have the same mathematical proportions as the world soul. The human body is fabricated out of the four elements that constitute the world's body, and only of these four elements. We could therefore say that the human being is a microcosm (a mini-universe). Two features enable us to establish a distinction between this microcosm and the world. Contrary to the body of the world, a human body is subject to destruction; and the human soul experiences a history that makes it pass into different bodies, as a function of its contemplation of the intelligible, both when it is separated from all bodies and when it occupies a body (*Ti.* 90e–92c). Very generally, then, a human being can therefore be considered as a composite, which provisionally associates a human soul with a body of masculine or feminine sex.

The constitution of the body

Two types of basic tissues make up the body of human beings: marrow and flesh. In order to fabricate marrow, the demiurge first chooses smooth regular triangles, which can produce fire, water, air, and earth of the most exact form. He mixes these perfect triangles together in order to constitute the marrow, with which he fabricates the brain, spinal marrow, and bone marrow; marrow is valued to this extent: it is here that the various parts of the soul will come to be anchored, as we shall see below. Then the demiurge continues his work: after irrigating and watering down pure earth, sifted with marrow, the demiurge fabricates the substance of bone, which he uses to fashion the skull, the spinal column, and all the other bones.

This time using elements composed of ordinary triangular surfaces, the demiurge then undertakes to constitute flesh, out of a mixture of water, fire, and earth, to which he adds a leaven made up of salt and of acid, which also consists of ordinary triangles. Flesh, when it dries, causes the appearance of a film, which is the skin. On the skull, the moisture, which comes out through the holes pierced in the skin by fire and is forced back under the skin by the air, takes root and gives birth to hair. Out of a mixture of bone and flesh without leaven, the demiurge fabricates the tendons, which he uses to attach the bones to each other. Finally, he fabricates the nails out of a mixture of tendons, flesh, and air.

The human body is thus reduced to the four elements corresponding to the four regular polyhedra, which are themselves constructed out of surfaces resulting from the arrangement of two types of right-angled triangles: isosceles and scalene. The mathematical qualities of these two basic triangles explain the difference between marrow, the anchor-point of the soul in man, and flesh, which is a completely mortal substance. Here even biology is mathematized, at least down to its most elementary level.

The destruction of the human body by illnesses is also described in mathematical terms at its most basic level, since it is ultimately explained by a dissociation or transmutation of its constituents, which can also be associated with the four elements, associated with the four regular polyhedra. Death occurs when the marrow in which the soul is anchored is gravely damaged; in this case, the bonds that hold the soul to the body relax and let go.

Three systems, the circulatory system (*Ti.* 77c–78a), the respiratory system (*Ti.* 78a–80d), and the nutritive system (*Ti.* 80d–81e), explain the orderly functioning of the human body, which is destroyed by several types of illness (*Ti.* 82b–86a).

The circulatory system is described by means of the metaphor of a garden. The description takes place in two stages. First to be mentioned are the networks of vessels (*Ti.* 77c–e) which transport the blood to all the parts of the body. Then Plato describes the circulation, within these vessels (*Ti.* 77e–78b), of the blood that results from the decomposition, through fire, of food. The circulation of blood has a double function: it ensures the nutrition of all the parts of the body, and it is the vehicle of sensation. The general term "vessels" is used here, for the distinction between veins and arteries was not established until Harvey in 1628.

The respiratory system (*Ti.* 78a–80d) is described on the model of a lobster pot. This pot contains two parts: a central cavity made of fire, which is inside the trunk, and two tunnels made of air, which pass through the nose and the mouth (*Ti.* 78a–d). This entire structure is subject to an alternative movement, which causes the thorax to rise and fall, and which continues as long as life does. Air, followed by fire, is in fact subject to a circular motion; it is breathed in through the nose and mouth, and breathed out through the body (*Ti.* 78d–79a) in a circular motion Plato assimilates to several other species of motion (79a–80c). The circularity of all the motions mentioned is explained by the will to account for their permanence.

Plato then moves on to the nutritive system (*Ti.* 80d–81e). Blood plays the main role in nutrition, and it results from the decomposition of food by fire, which gives blood its red color. This food may be in the form of drink or solid food (*Ti.* 80d–e) which is taken exclusively from plants. Fire, which, as we have just seen, follows air in the respiratory process, dissolves the food when it passes through the stomach, and forces the blood resulting from this decomposition to introduce itself into the vessels adapted to this purpose. Transported through all the parts of the body, the blood nourishes the marrow, flesh, and the whole of the body (*Ti.* 80e–81b). Mortal illnesses occur when the marrow, in which the various parts of the soul are anchored, because it is nourished inappropriately, degenerates and decomposes (*Ti.* 81b–e).

The illnesses that destroy the human body are divided into three groups. Some illnesses are due to an excess, a defect, or a poor distribution of the elementary components (i.e., the four elements) that constitute the human body (*Ti.* 81e–82b). Other illnesses come from the decomposition of tissues (flesh and tendons) which, as they liquefy, pollute the blood (*Ti.* 82b–84d). A third group of illnesses pertains to each of the elements that make up the human body: earth, water, air, and fire. These are fevers (*Ti.* 86a), certain illnesses that concern the breath (*Ti.* 84d–85a), and those relative to phlegm (*Ti.* 85a–b) and bile (*Ti.* 85b–86a).

Observation and Experimental Verification

The strength of Greek science resides essentially in its formal dialectical and demonstrative techniques. The ancient Greeks devoted considerable effort to developing an axiomatic system, and to using mathematics as the privileged instrument for understanding natural phenomena.

The empirical method also achieved considerable progress among the Greeks, in both research and practice. History and geography were the first domains to engage in the careful and exhaustive gathering of information; but this practice was soon extended first to medicine, and then to several domains: zoology, botany, and so on.

Nevertheless, empirical observation must be carefully distinguished from theoretical observation. Even if both types of observation overlap, all theoretical observation presents a deliberate character. In this regard, Aristotle rightly insists on the distinction between the observations carried out by fishermen in the context of their activity, and those undertaken in order to carry out a scientific investigation on fish. We must add another distinction, between observation properly so called, and awareness of its importance for research. To carry out detailed research on animals, plants, minerals, stars, musical notes, or illnesses, is one thing, but quite another to have an explicit methodology that attributes a precise role to empirical data within scientific research.

The two concerns just mentioned are present in Plato, albeit not at the level of self-awareness, and not to the same extent as in Aristotle. This general attitude can also be found in the *Timaeus*. Although several propositions made by Plato could be subjected to verification and eventually turned out to be false, the following nevertheless reveal that Plato was sensitive to a certain form of observation, and was not immediately opposed to all experimental verification. This is true of the movement of "planets" (*Ti.* 39a–d), of the greater density of gold than bronze (*Ti.* 59b–c), of the relation between the rapidity of a sound and its pitch (*Ti.* 67b), and above all the need for circular motion (*Ti.* 79e–80d) in a world that contains no void. These examples suggest that despite all the technical problems he had to face, Plato, in the *Timaeus*, formulates statements that truly pertain to cosmology, and that conflict neither with logic nor with sensory experience.

In ancient Greece, the search for certainty was often counterbalanced by an absence of empirical information. In addition, "evidence" and "experiments" were frequently used to corroborate a theory rather than to test it. In short, competitive debate, or *agōn*, seems ultimately to have furnished the framework in which the sciences of nature were developed in ancient Greece. The point was to establish a model of explanation, on the level of discourse, by presenting convincing arguments for it, rather than to impose it on the level of reality, by testing it against the facts to determine whether it could withstand the test or could better explain the facts than some other theory.

Two types of explanation, some technical and the others theoretical, can be advanced to explain Plato's reticence with regard to experimental verification.

Technical limits

The measuring operation may be considered the fundamental act of science. In order to progress, science must define particularly abstract concepts beforehand, among the first of which are units of measure. Let us note, for example, the tremendous importance assumed for the development of science by such units of measure as temperature expressed in degrees, acceleration, energy, electric charge, entropy, quantity of information as measured in bits, etc., and the elaboration of instruments allowing them to be measured. In Plato's time, known standards of measure, which concerned only length, weight, volume, and time, did not display any universality, since they varied as a function of individual cities, and remained highly unreliable, given the primitive nature of measuring instruments. In addition to the lack of appropriate abstract measures, another factor, no less decisive, also came into play: mathematics in Plato's time was in a particularly primitive state, and several of its developments now considered essential were still lacking. However, several examples dating from Hellenistic times reveal the ingenuity that was used to surmount or to get around these difficulties.

In view of what has just been said, it should be evident that, even if they attained a fairly advanced level in geometry, even if they succeeded in accomplishing technical exploits, as is shown by their architecture, their sculpture, and their ceramics, and although their methods of navigation implied the use of technical procedures, albeit primitive, the Greeks of Plato's time did not have available the tools which could have enabled them to conceive, define, and to put into practice experiments intended to verify their hypotheses in the domain of scientific knowledge.

Theoretical prejudices

Experimental verification, that absolutely decisive procedure of questioning Nature, escaped Plato, who, after setting forth his theory of colors, exclaims:

> To want to test [a physical phenomenon] under the control of experience (*skopoumenos basanon lambanoi*) would mean being unaware of the difference between men and the gods, for only a god . . . possesses the necessary knowledge and power, whereas among men none is capable . . . nor will they ever be in the future. (*Ti.* 68d–e)

For Plato, experimental verification thus implies the exact reproduction of Nature, a task that is as impossible for us as it was for him.

Let me mention just one particular aspect of a theory of verification, within the framework of a purely local, controlled, and repeatable experiment. Today, experimentation exhibits the following characteristic: in the course of an experiment, only a very limited number of parameters is allowed to vary, on the assumption that all the rest of the universe, with its enormous complexity, and its large number of variables, will exercise no influence on the experiment in progress: *ceteris paribus*, "everything else does not count." To reach this *ceteris paribus*, all the experimenter's ingenuity must be brought into play, which sometimes leads him to construct gigantic instruments such as particle accelerators. Now Plato, who clearly had neither the instruments, nor the units of measure, nor the mathematical language which would have enabled him to do so, did not try to carry out this type of experiment. This defect explains why the models of explanation he proposed in the *Timaeus* remain bereft of all operative value.

By neglecting observation, and especially by refusing experimental verification, Plato condemned his explanations to impotence. Why, indeed, should one prefer the explanations he proposed to others that were intuitively more plausible and used ordinary language, less abstruse than the mathematics whose use was reserved for a small number of specialists? On the level of the history of science, therefore, Plato remains an ambiguous figure – very modern when he appeals to mathematics and when he complies with the rigors of deductive argumentation, but very traditional when he holds observation to be worth little, and experimental verification to be impossible.

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