



## Problems and Methods of Early Greek Science

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Analyse d'ensemble des démarches intellectuelles dont témoignent les fragments et la doxographie des Milésiens et des premiers Pythagoriciens. Méthodes d'explication et de recherche mises en valeur au 6<sup>e</sup> siècle pour résoudre des problèmes touchant la cosmogonie, la structure de l'univers, les paradoxes de la nature et l'anthropologie.

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# PROBLEMS AND METHODS OF EARLY GREEK SCIENCE

BY HEINRICH GOMPERZ

This paper is based on a careful and prolonged re-examination of the entire material available for the study of the earliest phase of Greek scientific thought, *viz.*, the second half of the sixth century B.C.<sup>1</sup> The paper summarizes the *results* of this re-examination while the re-evaluation of the evidence and the re-interpretation of the fragments and doxographic reports must be reserved for separate treatment. It expresses an approach differing in two respects from the one commonly adopted. It will not be interested primarily in the views of individual thinkers, but will aim at a general description and logical analysis of the intellectual procedures characteristic of the age. And it will disregard the boundary line generally assumed to have separated the "philosophy" of ancient thinkers from their other scientific activities. Indeed, for such a separation there is not even an historical justification, since our chief authority, Theophrastus, presented the entire material indiscriminately as "Opinions of Physicists." And so far as this material itself is concerned, "philosophic" pronouncements could, if at all, be distinguished from others only by the criterion of being unusually sweeping and vague.<sup>2</sup> The following account will be based on the fragments of and doxographic reports on Thales, Anaximander, Anaximenes, Xenophanes,<sup>3</sup> Alcmaeon<sup>4</sup>

<sup>1</sup> Evidently, there would have been many advantages if the study could have been extended to cover the first half of the fifth century as well. Personal and local conditions have rendered this impracticable. Much of what will be said, however, applies to this period likewise.

<sup>2</sup> Indeed, in contrast to metaphysicians as well as anti-metaphysicians who agree in the view that the field of philosophy or metaphysics is different from that of science, I have come to the conclusion that it is rather by being vague and sweeping that philosophic or metaphysical differ from scientific propositions. This explains, on the one hand, why philosophy has so often been capable of exercising a real influence on the development of science but, on the other hand, also accounts for the fact that propositions when duly limited and made precise drop out of philosophy and are incorporated with a particular science. Indeed, this is only another way of stating what has so often been said, *viz.*, that philosophy has been the matrix out of which the particular sciences have gradually been developed.

<sup>3</sup> Xenophanes' theological and moral theories have also been analyzed, but, in order to render the material more homogeneous, have been abstracted from in this paper.

and, in part, of the earliest Pythagoreans.<sup>5</sup> It will fall into three sections dealing, respectively, with the *problems* discussed, the *methods of explanation* used, and the *methods of research* employed.<sup>6</sup>

### I. PROBLEMS DISCUSSED

The problems discussed may conveniently be assigned to four fields: Cosmogony, Paradoxology, Cosmology, Anthropology.

#### 1. Cosmogony.

How has the world come to be what it is at present? This had long been a familiar preoccupation. But it had prompted preceding generations only to describe the origin and pedigree of the gods who were believed to preside over the sundry regions and phenomena of the universe. This entire mythological scaffolding was now removed almost at one stroke, with a thoroughness that can hardly fail to surprise us: no traditional divinity is ever mentioned, and not even a passing thought is given to the possibility that earthquakes might be caused by the trident of Poseidon, or a storm by the thunderbolt of Zeus.

In its efforts to reconstruct the development of the universe, speculation was guided by certain presuppositions or postulates, some of which, at least, must be styled *a priori*, since they are in no way obviously suggested by experience. The most basic of these was the assumption that the development must have started with a state of things almost absolutely simple and homogeneous. "In the beginning" space was filled with one homogeneous mass: either a simple stuff or an all-inclusive mixture. This, with a term of Aristotle's, may be designated as the *principle* or *beginning*.

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<sup>4</sup> Alemaeon's lectures were probably given and taken down before the end of the sixth century. But even if this should not have been the case, we should yet be warranted in regarding him as the representative of the medical school of Croton which, as Herodotus informs us (III 131) flourished at the time of Polycrates of Samos, i.e., about 525 B.C.

<sup>5</sup> The reason why the Pythagorean material could be used in part only is that most of it differs too widely in character from the rest to permit a common description. In contrast to all other thinkers of the age, the Pythagoreans did not keep science clear of mythology, and their specific approach to science by way of number-theory and, in particular, of the holy *tetraktys* could only be described and analyzed in a separate paper.

<sup>6</sup> Quotations, where no other indication is given, will refer to H. Diels, *Die Fragmente der Vorsokratiker*, 5. Auflage, her. v. W. Kranz (Berlin, 1934 ff.).

From this there must have arisen, in some way or other, a plurality of entities, conceived to be the essential constituents of reality as now known to us: entities which we may style the *fundamentals*. These were of two kinds: either what was generated was a set of *qualities*, such as Hot and Cold, Moist and Dry, or else it was a set of substances, such as fire, air, water and earth, or perhaps we ought rather to say, of states of aggregation, *viz.*, fire, gases, liquids and solids. In either case, these fundamentals were definitely of an abstract or *typical* nature: it was felt that what had to be pointed out was the number and kinds of material that had entered into the structure of the universe—in the same way in which a person who wanted to tell us how a house had been built might begin by stating that the materials available for the purpose had been marble, bricks, wood and iron. From these fundamentals the world was then supposed to have grown by a series of steps described differently by different thinkers, but all conforming to the postulate that these developments must be intelligible by being analogous to events familiar to us from common experience.

It is not always easy to distinguish the qualities from the substances. The Hot, e.g., manifestly tends to be confused with fire, and the Moist with water. Nevertheless, the two kinds of fundamentals differ in one important respect. The substances have definite location and are rather inert, whereas the qualities are all-pervading and possess a more dynamic character. The same duality, about a century later, may be traced in Greek medicine: there was a more materialistic view according to which man consists of the four humors: phlegm, blood, bile and black gall; but there was also a more dynamic theory conceiving the human body as a battle-ground on which the Hot strives to dominate the Cold, and the Moist the Dry.

How do the fundamentals emerge from the principle? Here two cases must be distinguished. Sometimes one of the fundamentals was held to be itself the principle (that is to say, “in the beginning” all was water, or air, or fire); in this case, the other fundamentals must have arisen from it by a process such as condensation and rarefaction, or kindling and extinction. But when the principle was different from all the fundamentals and was conceived rather as a sort of mixture, then the fundamentals must have been segregated or “separated out” from it, and for this process

of differentiation some form of movement—perhaps in the nature of a vortex—was mostly held responsible.

## 2. Paradoxology.

By this I mean the study of what the ancients termed the “paradoxes of nature,” i.e., of *unusual* and *irregular* phenomena, such as earthquakes, thunderstorms and eclipses. By these—which formerly mythology had tried to account for—the scientifically-minded were evidently very much puzzled, and their concern with them was almost, if not quite, as great and apparently independent of their preoccupation with cosmogony. At any rate, paradoxology ranked second only to cosmogony among the topics of speculation. It is true, of course, that the unusual and irregular cannot be strictly delimited from the usual and the regular. But it is, I think, a highly significant fact that, for instance, the *eclipses* of the moon appear to have called for an explanation much more urgently than its *phases*. The latter everyone took for granted; they determined the rhythm of private and even of public life; it was the former that took people unawares, startling them and challenging their powers of understanding.

## 3. Cosmology.

One might have expected that the problem: What is the world like right now, what are its structure and its course? would always and everywhere be in the foreground of scientific thought. That was evidently not the case in sixth-century Greece. At that time and in that area the intellectual effort was directed to the past even more than to the present, and to the extraordinary even more than to the ordinary. The problems of cosmology were definitely felt to be less urgent than those of cosmogony and paradoxology.

Nevertheless, they too could not fail to arise. On the one hand, the cosmogonic tale had, so to speak, necessarily to lead up to a “happy end”: it was impossible to recite the steps by which the world had come to be what it is without mentioning what it was like at present. If the account of the transformations heaven and earth had undergone was to be satisfactory, something had also to be said about their present shape and arrangement. On the other hand, the explanation of abnormal phenomena presupposed and called for a background of normality: it was impossible to account for thunderstorms without implying how clouds are formed and how winds arise. And even that was not all. In the cosmo-

gonic accounts certain everyday experiences had to be used as patterns which, sooner or later, to a certain extent at least, became interesting in their own right: a physicist could not, in the long run, go on asserting that all air had originally arisen from water by evaporation or, the other way round, that all water had first been formed from air by precipitation, without realizing that evaporation and precipitation were even now going on before his eyes. Finally, now and then, a thinker made a statement of a very general and very vague character, evidently meant to apply to present as well as to past developments, such as: "What comes to be, must pass away,"<sup>7</sup> or: "Wherefrom a thing has emerged therein it should again be resolved,"<sup>8</sup> and such pronouncements also may, at least in part, be assigned to the field of cosmology.

#### 4. Anthropology.

Some thinkers occasionally touched on the problem how the human race had arisen and what the first man had been like,<sup>9</sup> and many had something to say about the soul, that is, about the entity supposed to leave men in death and to account for their life and their movements as long as they were alive.<sup>10</sup> But a systematic study of the human body was first undertaken within the guilds of the physicians.<sup>11</sup> Within this new field speculation on the process of begetting and on embryology corresponded to cosmogony; pathology to paradoxology; and the investigation of the healthy body, i.e., anatomy and physiology, to cosmology.

### II. METHODS OF EXPLANATION

To explain a phenomenon means to show that, even though at first sight it may appear very unfamiliar, yet, on closer scrutiny, it turns out not to be entirely unfamiliar, since it exhibits certain *analogies* with other phenomena, familiar to us from common experience. And a phenomenon functioning in this way as an explanatory analogy, may be styled a *thought-pattern*. Thus we may say that the methods of explanation adopted by the earliest Greek scientists consisted almost exclusively in the use of certain definite thought-patterns.

<sup>7</sup> Xenophanes, A 1 (19).

<sup>8</sup> Thales, A 13 (end); Anaximander, B 1.

<sup>9</sup> Anaximander, A 30; Xenophanes, A 33 (6).

<sup>10</sup> Thales, A 22; Anaximander, A 29; Anaximenes, B 2; Xenophanes, A 50.

<sup>11</sup> Actually, with respect to the field of sixth-century anthropology, the scanty remains of Alemaeon's lectures constitute our only source material.

So far as I can see, the thought-patterns used by them were chiefly four; but the use of two others may also occasionally be traced.

1. The first of these may be termed the *biological* thought-pattern, and might, were there need, be subdivided into the biological proper, the anthropological and the theological. That is to say, phenomena are accounted for by comparing them to processes such as growth and decay, to the results of design and deliberation and to the achievements of superhuman wisdom and power.

2. A second thought-pattern may be styled *political*. The world is understandable in so far as it is analogous to a city. The regularities of nature correspond to the rules that govern civil life.

3. A third thought-pattern might be designated as that of *artistic creativity*. The scientist takes the attitude of an architect about to found a city or to lay out a temple. He feels that certain forms, measures and proportions are called for under the circumstances, and thence he immediately concludes that the facts actually conform to them.

4. Finally, there is the *mechanical* thought-pattern, that is to say, very often a phenomenon is understood by being assimilated to a procedure used in the crafts.<sup>12</sup>

<sup>12</sup> Two further thought-patterns seem occasionally to have been used. The fifth might be called the pattern of a *well-* or an *ill-ordered household*, or, in more scientific language, of *objective teleology* or *dysteleology*. In a well-ordered household things are so disposed and arranged, from time immemorial, as to serve their purpose; should this not be the case, the household would be out of order. Now, we are told (Anaximander, A 14; comp. Anaximenes, B 3) that the material available for the building of new worlds must be boundless *lest it ever fail*; but we are also told (Xenophanes, A 41a) that the sun sometimes drifts into uninhabited regions where it can do no good and that even according to the ordinary course of things (Xenophanes, A 42) while the sun is useful, the moon is not but just "runs along." The sixth thought-pattern I should term that of *pure factuality*. It is not correct that causality is a universal category of thought. Man is interested in causes only in so far as their knowledge may serve him to bring about the repetition of a desirable or to avoid that of an undesirable experience. But when he feels the occurrence of a phenomenon to be out of his reach he gives little thought to its causes. Of all the persons who state that "this is a nice morning" not one in ten thousand raises the question *why* this is the case, and the same is true with regard to the fact that a breeze is blowing from the North or that the waves of the sea are running high. In all such instances we are completely satisfied to realize that a certain state of things *just happens to be the case*. Now, it appears that the early scientists accounted for at least one type of assumed facts by assimilating them to such as "just happen to

Now, a closer study of the use made of these different thought-patterns has revealed a surprising fact which does not appear to have been given hitherto due consideration. The part played by the different thought-patterns in the investigation of different fields is not at all the same. In cosmogony the biological pattern is used without any reserve: the universe is a living being; it realizes certain schemes; it is hailed as divine. In cosmology the political and the artistic pattern seem to dominate. The kosmos is like a city; it is surrounded by the celestial vault as the city is surrounded by its walls; the order of nature is based on an equilibrium of rights and obligations (day, e.g., has a right to last a certain time, and night a corresponding time),<sup>13</sup> and should this order ever be violated, such violation would have to be avenged.<sup>14</sup> On the other hand, it is assumed to be a fact that the shape of the earth is that of a drum three times as broad as it is high and that the distances of the stars, of the moon and of the sun from the center of the earth are in the ratio of 1:2:3—not because any measurements have been made to this effect but because it is *fitting* that such should be the case.

But when we come to the field of paradoxology or, to use a still more general expression, when the problem is how to explain any concrete phenomenon whatsoever, all this appears to be forgotten and the mechanistic thought-pattern seems to hold exclusive sway. Generally speaking, the world is divine, just and beautiful; but in the concrete it is all a matter of tossing waves, clouds torn asunder, clods hitting the ground, vapors catching fire. It is well known that this kind of inconsistency (if such it be) was bitterly charged by Plato and Aristotle against Anaxagoras; what is generally not realized is that their attack might, with almost the same degree (or

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take place": these assumed facts were the first movements or changes (in the nature, e.g., of condensation and rarefaction) supposed to have brought about the development of the fundamentals from the principle. In other words, the original state of things, as it existed "in the beginning," comprised change and motion—in the same sense in which the air and the sea are changing and moving. The significance of this insight consists in this, that it enables us to discard as illegitimate the concept of *hylozoism*. "When a thing *x* was held to move without being moved by another thing *y*, it must have been considered to move itself and hence to be a living thing." That is not a valid inference. The Greek scientists no longer believed that winds were moved by gods but neither did they hold them to be living beings.

<sup>13</sup> Heraclitus, B 94.

<sup>14</sup> *Ibid.*, and Anaximander, B 1.

the same lack) of justification, have been directed against any one of his predecessors.<sup>15</sup>

We ought not, however, to speak of the mechanistic thought-pattern indiscriminately, we ought rather to distinguish between the mechanics of solids, of liquids and of gases. The latter were

<sup>15</sup> In order to impress this important fact upon the reader with due emphasis it may be worth while to survey rapidly the chief pre-Anaxagorean thinkers and to show how they all, in some form or another, bear witness to the same antinomy. According to Thales (A 22) "all is full of gods," but (A 15) earthquakes are accounted for by the waves of the waters on which the earth is afloat. According to Anaximander we should suppose that the kosmos is steered by the Unaging and Immortal (B 2) and, at any rate, that what happens must conform to the standards of justice and morality (B 1); but when it comes to the explanation of eclipses (A 11, 4), thunderstorms (A 23) and earthquakes (A 28), it is all a matter of openings obstructed by dirt, of compressed air exploding and rending clouds asunder and of the impact of air-currents that penetrate beneath the surface of the earth and shake it. By Anaximenes the divine nature of the universe may have been somewhat less emphasized (A 7, 1; A 10), but the thoroughly mechanistic character of his explanations is beyond doubt. The case of Heraclitus is particularly instructive: the universe is God and it is steered by wisdom (B 67; B 32; B 41; B 108); but, as far as the phenomena of paradoxology were concerned, Theophrastus informs us that Heraclitus "accounted for almost everything by means of the exhalation arising from the sea" (A 1, 9)—which, however, was not the only one he assumed, since he held that there were exhalations from land as well as from the sea and that in both cases they might be either bright or dark. Similarly, Xenophanes was most emphatic in proclaiming the divine character of the universe, or at least of the heavens: God is all eye, all ear and all thought. But, as is plain from the doxography, the idea never occurred to him that this principle of divine foresight might be used for the purpose of accounting for any details in the natural course of events: this course is determined on the one hand by the law that land and sea are alternately mixed up with and again separated from each other and on the other hand by the fact that from the sea there arise vapors soon transformed into clouds which in part are re-transformed into water, while others catch fire and, being borne along by air-currents, produce the illusion of luminaries moving in permanent orbits. In Parmenides the duality of apparently incompatible points of view has always been felt to be most striking. In "truth" all things are one; there is no change; nothing moves. But according to "appearance" the world has come to be by the interaction of two elements, light and night (B VIII 53 ff) and it is on the prevalence of these that even now the differences of youth and old age (A 46 a), of waking and sleeping (A 46 b) and even of superior and inferior intelligence (B 16) depend. We cannot trace such a duality in Melissos, but if our doxography is reliable, even Zeno after having demonstrated (or before demonstrating) the impossibility of any multiplicity did not disdain to indicate how the universe had been built up out of a plurality of elements (A 129). And so we have come down to poor Anaxagoras who was so severely taken to task for an inconsistency which certainly was not specifically his own.

the universal favorite. The boiling of water and the burning of incense provided the most widely used patterns. Steam and smoke, vapors and exhalations were felt to be the panaceas for human ignorance: being for the most part invisible and intangible they were excellently qualified to play the rôle which later fell to *forces* and *energies* and which Descartes, for instance, assigned to the *vital spirits*.

The most significant scientific issue of the age (and of the ages to come) concerned the heavenly bodies (whose divine nature was, in most cases, ignored though not denied). Should their interpretation be based on the mechanics of gases or of solids? One party<sup>16</sup> held that the world was uniform with regard to stuff and to law; thence they concluded that the heavens were but part of the atmosphere and their study an extension of meteorology: the celestial luminaries were burning vapors or clouds. The other party<sup>17</sup> felt that "the world above the moon" differed essentially from that beneath her: it was built out of another stuff and on a different plan; it formed the subject-matter of another science, and the regularity of its revolutions had to be accounted for by mechanical devices such as wheels and revolving spheres.

And this discussion led up to a further dilemma. If the heavenly bodies were solids, they were likely to be persistent: to-day's sun, e.g., would be conceived as identical with yesterday's, and its orbit would have to be worked out in such a manner as to account for its daily return from West to East. But if the sun is but a burning cloud, this intricate and puzzling problem might be dispensed with altogether, or rather, it would reveal itself as a pseudo-problem: the sun may then be conceived as being formed anew each day and instead of assuming a persistent *object* "sun" it will suffice to posit a meteorological *law* of daily sun-formation.<sup>18</sup>

### III. METHODS OF RESEARCH

In a general way, the following statements may, I think, be made with reasonable assurance. "As might have been expected in an age whose central problem was cosmogony, i.e., a set of unobservable and unrepeatable phenomena, and which, moreover,

<sup>16</sup> Anaximenes, Xenophanes, and later Atomists and Epicureans.

<sup>17</sup> Anaximander, the Pythagoreans and later Plato and Aristotle.

<sup>18</sup> This was the view of Xenophanes, whom Alemaeon and Heraclitus followed only in part.

lacked all magnifying devices, the need for increased factual knowledge and for testing assumptions by experience was hardly felt. The facts to be explained were supposed to be matters of common knowledge, and any endeavor to account for them was essentially like the effort to solve a riddle. A scientific hypothesis was a (more or less fortunate) guess and the only criterion of its validity was its intrinsic plausibility. No one, however, could feel quite sure of having guessed aright and hence dogmatic pronouncements were sometimes quaintly introduced by professions of universal agnosticism.”

As soon as we try to be more specific than this, we have to grapple with a very serious difficulty: were two thoughts linked together by an ancient scientist or by a late doxographer? Even with regard to such questions there will be probabilities, but the degrees of these probabilities will be deplorably small.

As a rule it seems that views were stated in a dogmatic fashion. Sometimes such views were in agreement with tradition or with opinions expressed by predecessors. But often there was evidently deliberate disagreement with “what others have held.”<sup>19</sup> However, within the domain of science (as distinguished from theology and politics) the grounds for such disagreement were hardly ever stated in so many words. Sometimes the reason why a scientist differed from his predecessor may be inferred from the views by which he replaced the latter’s theories;<sup>20</sup> but that is the exception rather than the rule.

The theories themselves do not lack complexity. Very often, several theories are interdependent and express a connected view. And even one and the same theory may sometimes be of considerable complexity. A theory, e.g., concerning the causes of earthquakes is organized in the following way:<sup>21</sup> “All quakes are directly caused by clods breaking away from the mass of the earth. This process of breaking away may itself be due to four or five different causes” (three of which a predecessor had apparently already pointed out). “The breaking away of the clods produces quakes in two different ways. In the first place, while the clods break

<sup>19</sup> Anaximenes, A 7 (6).

<sup>20</sup> Anaximenes’ theory of quakes compared with that of Anaximander, according to Seneca, *Nat. Quaest.*, VI 10.

<sup>21</sup> Same passage, for which there are very specific reasons not to hold Seneca responsible.

away, the masses from which they break away are shaken by an effect of recoil. Secondly, when the clods reach the ground, they either hit a solid surface or fall into stagnant waters: in the former case they cause repeated shocks like a ball falling to the ground; in the latter they produce a flood like a stone thrown into a pool." In this case as also in a few others *analogies* are adduced with the evident intent of carrying *conviction*, but in more numerous instances the function of analogy is simply to illustrate an alleged state of affairs (e.g., "the stars move round the earth as the hat moves round the head").<sup>22</sup>

Arguments are sometimes of a purely tautological character, for instance: "Clouds, rains, springs, streams all stem from the sea. For if the sea were not, all these would not exist. But actually, the sea does produce them."<sup>23</sup> But in the great majority of cases arguments are based on general contentions implied and—if one may say so—dogmatically presupposed, though mostly not explicitly stated. These general contentions are of two kinds: they are either mere *postulates* or *assumptions*, more or less independent of experience; or else they are rather statements of *general facts* based on a more or less sweeping and superficial induction and thus coming close to what we should term *laws of nature*.

The *postulates* again cover statements of various types. Some amount to moral demands and judgments of value. "Violations of the order of things must in justice be avenged."<sup>24</sup> "The material for the building of new worlds must never fail."<sup>25</sup> "Whence a thing has arisen, thither must it return."<sup>26</sup> Some of these postulates that we feel tempted to style purely metaphysical express what we might term exigencies of thought, e.g., "Qualities persist even when 'dominated' by their opposites and hence not traceable in experience";<sup>27</sup> "Where there is apparent change, there must be an unchanging substrate."<sup>28</sup> Very often a postulate expresses

<sup>22</sup> Anaximenes, A 7 (6). Here is a list of demonstrative and another of merely illustrative analogies. *Illustrative*: Thales, A 14, A 15; Anaximander, A 10, A 11, A 21; Anaximenes, A 7 (6); A 12, A 14, A 15, A 19, A 20. *Demonstrative*: Anaximenes, A 17, A 20 (?); B 2; Seneca, *N. Q.*, VI 10; Alcmaeon, A 5 (25), A 12; Anon. Pyth., B 40 (?).

<sup>23</sup> Xenophanes, B 30.

<sup>24</sup> Anaximander, B 1; Heraclitus, B 28, B 94.

<sup>25</sup> Anaximander, A 14; Anaximenes, B 3.

<sup>26</sup> Thales, A 13; Anaximander, B 1.

<sup>27</sup> Alcmaeon, B 4.

simply a characteristic feature of a scientist's theory which to him appears to be self-evident and not to need any proof, e.g.: "The earth is a flat object";<sup>29</sup> "The earth is freely suspended in the center of the universe";<sup>30</sup> "The distances of the heavenly bodies from the earth correspond to the proportions underlying the musical intervals";<sup>31</sup> "There must have been a first man."<sup>32</sup> Finally, an hypothesis that affords a possible and convenient explanation of a fact is often dogmatically asserted as true, no thought being given to empirical verification even where this, or rather the falsification of one, would be easy or, at any rate not impossible. As illustrations, consider the following statements: "Since in death the blood completely recedes from the veins, it must incompletely recede during sleep"<sup>33</sup> (and no one is struck by the fact that a person asleep is neither less warm nor less rosy than one awake). The female mule is barren because her womb is not sufficiently open to admit the sperm; but the male mule is barren likewise, his sperm being too cold and too light"<sup>34</sup> (and we may be sure the female mule was not dissected nor was any effort made to weigh the sperm of the male or to determine its temperature). "The child follows the sex of that parent who has contributed 'more' during the act of generation."<sup>35</sup>

*Laws of nature*, again, exhibit extremely varying degrees of generality, and range from such as are almost true through those that are half-true (or at least contain an element of truth) to the entirely fantastic. The following list may give an idea of them. "What comes to be, must pass away."<sup>36</sup> "All things age."<sup>37</sup> "A thing x does not move another thing y unless x have a soul."<sup>38</sup> "A thing x which is at rest does not move unless it be overpowered by another thing y." (This, incidentally, is a crude way of empha-

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<sup>28</sup> This point of view, definitely over-emphasized by Aristotle, nevertheless doubtless underlies passages like Anaximenes, A 7 and Heraclitus, B 30-31.

<sup>29</sup> Anaximenes, A 20.

<sup>30</sup> Anaximander, A 26.

<sup>31</sup> The fundamental assumption of Pythagorean cosmology.

<sup>32</sup> Anaximander, A 30.

<sup>33</sup> Alemaeon, A 18.

<sup>34</sup> Alemaeon, B 3.

<sup>35</sup> Alemaeon, A 14.

<sup>36</sup> Xenophanes, A 1 (19).

<sup>37</sup> Anaximenes according to Seneca, *N. Q.*, VI 10.

<sup>38</sup> Thales, A 22.

sizing one aspect of the principle of inertia.) "If a thing *x* be surrounded by several other things *y*, *z*, *u* . . . , it can be overpowered and moved by that one only to which it is closest in space."<sup>39</sup> "As a consequence of continuous evaporation the sea must gradually disappear."<sup>40</sup> "Where there is a break, there is a recoil."<sup>41</sup> "The factors responsible for the characteristic weather of the different seasons must be such as are capable of causing heat and cold," and hence the stars cannot be such factors.<sup>42</sup> "Flat objects remain afloat" (on air as on water).<sup>43</sup> "Clouds moved in certain ways begin to glisten."<sup>44</sup> "It is things hollow that sound."<sup>45</sup> "Sounds are produced by moving bodies and their pitch is in proportion to the velocity of these bodies." But "a sound may be heard only against a background of silence."<sup>46</sup>

Perhaps the most characteristic feature of sixth-century science, however, is its attitude toward factual verification. That it tells in favor of an hypothesis or assumption if facts in agreement with it may be pointed out was not at all overlooked. On the contrary, in a considerable number of instances it is possible to show that facts on which a theory had plainly not been built to begin with were subsequently introduced as supporting or corroborating it, in a spirit that might adequately have been expressed by words such as "*And indeed it is the case that . . .*" But two things, it would seem, were never realized. First, that it makes a great difference whether a corroborating fact is a *real* fact or whether it is itself only *an assumed* and hypothetical fact—indeed perhaps no less hypothetical than the hypothesis it is supposed to corroborate. In the second place, it was completely overlooked that facts may bear out a theory *to a greater or lesser extent*. A theory was felt to be an indivisible whole and was supposed to be corroborated *in its entirety* by any (real or assumed) fact in agreement with any assumption or belief forming part of the theory. This important point may perhaps best be illustrated by one particular instance which, moreover, is also of special interest because—quite excep-

<sup>39</sup> Anaximander, A 26; Parmenides, A 44.

<sup>40</sup> Anaximander, A 27.

<sup>41</sup> See note 37.

<sup>42</sup> Anaximenes, A 14 end.

<sup>43</sup> Anaximenes, A 20.

<sup>44</sup> Xenophanes, A 39 and 45.

<sup>45</sup> Alemaeon, A 5 (25).

<sup>46</sup> Anonymous Pythagoreans, B 35.

tionally!—the corroborating facts were not matters of common knowledge, but had been discovered by the scientist himself by means of specific observations and investigations. Xenophanes had figured out a theory according to which sea and land will gradually be mixed up with each other until a state of universal “muddification” is reached, incompatible with the survival of mankind. Then, sea and land will little by little be separated again, the mud will be dried up and a new race will be formed. And such alternating periods will succeed one another again and again, indefinitely. Now, *in support of this theory*,<sup>47</sup> Xenophanes adduced two series of observations. First, shells are found in mid-land and even on hill-tops. Secondly, in certain places (Malta, Syracuse, Paros) the rock exhibits imprints of fossils that could only have originated at a time when the rock was mud and must have been hardened as the mud was dried up. Xenophanes did *not* see that these facts do not bear out either his assumption that “muddification” took place everywhere at the same time or his contention that a new period of “muddification” is impending, but that the facts quoted by him would in themselves tell rather in favor of the view of one of his predecessors, according to which the cosmic process is one of progressive desiccation, ending with the total disappearance of the sea.<sup>48</sup> This was because he compared *his theory as a whole* with the evidence and held the latter to corroborate the former since it was in agreement with *one element* of his hypothesis.

In other instances we are less completely informed, but the methodological situation was probably much the same. I subjoin a list (characterizing such “corroborating” facts as are purely hypothetical by a question-mark.)<sup>49</sup>

“The earth floats on the sea. Quakes take place when it is rocked by the waves. *And indeed*, when there is a quake, new springs appear in most cases, comparable to the water that leaks into a boat rocked by the waves.”<sup>50</sup> “The regularity of the celestial movements is due to the fact that the orbits are in truth wheels of opaque vapor containing fire. This fire is visible through circular openings in the wheels and it is these openings that we

<sup>47</sup> “Saying he disposed of the following proofs,” Xenophanes, A 33 (5–6).

<sup>48</sup> Anaximander, A 27.

<sup>49</sup> It must be understood that the arguments referred to in the following list are *reconstructions* and are not, *as such*, to be found in the evidence.

<sup>50</sup> Thales according to Seneca, *N. Qu.*, VI 6.

designate as sun, moon and stars. *And indeed*, it is when these openings are obstructed (?) that the so-called eclipses ensue."<sup>51</sup> "Earthquakes are due—directly or indirectly—to cracks in the earth's surface caused either by desiccation or by heavy rains. *And indeed*, quakes mostly occur in times either of drought or of floods."<sup>52</sup> "Heat is the effect of expansion, cold of compression. *And indeed*, the breath is cool when compressed by the lips but warm when allowed to expand."<sup>53</sup> "When the winds tear a cloud asunder, a flash of lightning is seen. *And indeed*, a flash of white light is also seen when the water is split by the oars."<sup>54</sup> "The brain is the general organ of sensation. The sensations are conveyed from the particular sense-organs to the brain by certain channels. *And indeed*, the senses fail a person who suffers a concussion of the brain because in such a case the brain is displaced (?) and thereby those channels are interrupted(?)." <sup>55</sup> "We could not see if there were no fire in the eye. *And indeed*, this fire is seen when the eye is hit."<sup>56</sup> "Disembodied souls live on mere odors. *And indeed*, even some animals (bees) support themselves in this same way."<sup>57</sup>

Of the five thinkers on whose theories our discussion has mainly been based the two latest introduced their expositions by a sort of skeptical proviso. "The precise nature of the gods and of all the things I am discussing no man has ever beheld nor will there ever be such a one as beholds it . . . (mere) opinion is spread out over them all. . . . But in so far as they have revealed themselves to human vision . . . let us take these opinions as (at least) resembling the truth."<sup>58</sup> "With regard to things mortal the gods attain to precision, but as far as men may judge by indications. . . ."<sup>59</sup> And in the following century this chorus was joined by at least two more voices: "The whole (truth) may not be beheld by men nor learned about or grasped by their minds and even thou mayst learn

<sup>51</sup> Anaximander, A 11 (4).

<sup>52</sup> Anaximander, A 28.

<sup>53</sup> Anaximenes, B 1.

<sup>54</sup> Anaximenes, A 17.

<sup>55</sup> Alemaeon, A 5 (26 end).

<sup>56</sup> Alemaeon, *ibid.* (beginning).

<sup>57</sup> Anonymous Pythagoreans, B 43, taken with Heraclitus, B 98.

<sup>58</sup> Xenophanes, B 34, 36, 35.

<sup>59</sup> Alemaeon, B 1.

. . . not more than what mortal thinking power reaches up to.”<sup>60</sup> “True knowledge of reality is not available, but I define it as best I can.”<sup>61</sup> We have good reasons for assuming first, that these skeptical introductions did not weaken or otherwise modify the dogmatic tenor of the subsequent expositions, and furthermore, that they were meant to cast a shade of doubt on particular explanations rather than on general principles, postulates and assumptions.<sup>62</sup> Indeed, we must realize the paradoxality—not to say the enormity—of the undertaking of making pronouncements and even writing books on those regions and domains of nature which were supposed to be, once for all, excluded from human experience or, as one of those authors put it himself, “on the non-apparent.”<sup>63</sup> If they felt that, here, they were on slippery ground, their feeling was only too justified. And yet it is difficult to believe that the curious unison of four (more or less) independent voices should be due exclusively to the operation of a scientific conscience that made itself felt in four introductions, only to be forgotten or neglected in the works themselves. Perhaps there was an extrinsic motive contributing to the result. To concern oneself with things “high up and beneath the earth” was not in good repute. It was the province of diviners, astrologers<sup>64</sup> and treasure-hunters. It is not at all improbable that the earliest scientists found it to be in their interest to draw a line of demarcation between all such people and themselves: “They may pretend to have certainty concerning these hidden things; we simply communicate our ideas.”<sup>65</sup>

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<sup>60</sup> Empedocles, B 2.

<sup>61</sup> Ecphantus, no. 1.

<sup>62</sup> Xenophanes, in particular, certainly exempted theology from the sphere of possible doubt, since here he started from what a god *had* to be in order to be a god. In this I entirely agree with Mr. Deichgraeber, *Rheinisches Museum* (1938), 30.

<sup>63</sup> The title Alcmaeon, B 1, gives as that of his lectures.

<sup>64</sup> Astrologers in the modern sense: Heraclitus, B 105.

<sup>65</sup> But it must also be noted that all the four skeptical utterances come from Lower Italy and Sicily (Elea, Kroton, Akragas, Syracuse). Possibly the motive indicated, or some other motive, operated in those parts with more than its usual force. The region was a hot-bed of religious sects and mysteries. Perhaps a prosecution for impiety might have been more likely and at the same time more dangerous there than elsewhere.