

The philosophic and biological views of the “atomic” philosophers, Leucippus and Democritus

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Abstract

The purpose of this study was to describe and highlight the work of the so called “atomic” philosophers Leucippus and in particular, his student Democritus, after an extensive research of works written by numerous ancient Greek philosophers and historians. The work of these two philosophers is groundbreaking, covers a wide spectrum of science and humanities and shows their high level of scholarship, erudition, and analytical thinking. Their ideas are often mentioned by other ancient Greek philosophers, with positive and sometimes negative criticism. Their theories were spread later, in ancient Rome, Byzantium, the Medieval Western Europe and in our times.

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Introduction

The city of Avdera in Thrace, close to Chalkidiki, in northern Greece and opposite the island of Thasos is considered as the birthplace of Democritus. We are not sure if Leucippus was also born there. Anyhow, Avdera, holds a very important place in ancient history, philosophy and science and was also the birthplace of other key figures of ancient Greece such as Nikenetos the epic poet and Protagoras, as mentioned by Stephen of Byzantium in his treatise *De urbibus* [1]. The philosopher Anaxarhos, the grammarian Ekateos, the mathematician Vionas and the historian and engineer Diocides were also born in Avdera.

Leucippus: Democritus’ teacher

The life of Leucippus

Leucippus was probably born in the city of Avdera, while others mention as his birthplace the island of Milos or Elea, a Greek colony in Italy, or Miletus in Asia Minor [2-5]. He may have been a student of the philosopher Zeno of Elea (490-430 B.C.) [2], of Pythagoras of Samos (570-495 B.C.) [3], and of Parmenides of Elea [6]. His major works include the *Great World System* (“Μέγας Διάκοσμος”) and *About the Mind* (περί Νου), from which Democritus borrowed his terminology and developed his own theories in a book under the same title [6].

The work: *Great World System* constitutes rather a collection of philosophical theories of the School of Avdera, as was the Hippocratic collection used for the class of philosophy of the Hippocratic school [7]. Many of these theories were adopted by other philosophers such as Diogenes of Apollonia (fl. 425 B.C.) and Epicurus of Samos (341-270 B.C.) [8].

The work of Leucippus - The beginning of the atomic theory

It appears that the formulation of the atomic theory began as an effort to overturn “Eleatic monism”, doctrine of “one alone”, as established by Parmenides from Elea and his successors, who refused to accept any evidence coming from the human senses and the world of physical phenomena. The Eleatic school accepted the notion of “One” which is the only existing entity, is global, always complete, including everything in the world, and beyond which nothing exists. Unlike the Eleatics, the atomic philosophers studied genesis, deterioration of all beings and phenomena which can be observed by human senses. Leucippus (Fig. 1) and Democritus (Fig. 2) supported the view that the elements are “complete” and “void.” They called the full and solid: “complete” or “being,” and the empty and diluted: “void” or “not being”; they therefore certified that being does not exist more than the non being, since non-void cannot exist any

less than void [9]. Leucippus explains that being “is not one, but is infinite in numbers of beings, and invisible” [10], and “movement is eternal” [11]. He calls “atoms” the “minimal bodies” [12], that “they cannot be divided because of their size” [13] and that “movement is necessary for all things beings and non-beings, i.e. invisible things” [14].

Leucippus and his followers believed that indivisible atoms must be on move, and therefore, they have to be separated by void and that atoms “are unchangeable because they are compact, solid and do not have any void.” Also: “the division of matter depends on whether there is void and on its quantity within various bodies” [15].

According to Leucippus, there are innumerable worlds consisting of innumerable elements emanating from and dissolving into these elements [16]. According to Leucippus, the process of separation from an infinite mass created atoms of various forms and shapes. These atoms were assembled within the great void, and then the lighter ones were separated from the heavier ones through the process of continuous spin; the lighter ones occupied the most exterior layer, while the heaviest ones remained implicated and thus, formed the first spheroid world. These theories of Leucippus accepted by Democritus later can be considered as predecessors of the recent Big Bang theory.

Atoms are eternal, unalterable, not subjected to the processes of birth and deterioration and through various combinations and segregations they have created everything that is subjected to change. It was very difficult for these philosophers to overlook as they did the theory of Parmenides on the characteristics of the entity of “One.”

Leucippus wanted to exclude the factor of chance, implying instead that every phenomenon has or must have a deterministic interpretation. This was based on the initial assumptions about atoms and the constant movement or “*αεικίνητον*” of everything in the world. This movement caused collision of atoms, which then unite or repel from each other. This repulsion-attraction type of movement is the basis for the atomic philosophers’ explanation of all physical phenomena. There is no need to interpret the primordial principle of motion; they thought, that since motion is eternal and has no obvious starting point, it simply does exist. Atoms acquire the ability to move, simply because that ability exists within the void. In contrast to Parmenides, who excluded the possibility of non-being, the atomic philosophers believed that the void or non-being exists equally with the being, but in a very different manner. Geometric forms, for example, are immaterial, but nevertheless exist, as the Pythagoreans also had stated.

Historians do not agree on what the atomic philosophers ment by “void.” Some share the view of Aristotle that it is the empty space, whereas others believe that the gap implied by “void” marks only the absence of being, while atoms represent being. In other words, the gap is identified with the absence, which, in turn is defined by the oposite of being, which is connected with the meaning of presence. In fact, the non-being is the space that exists between the atoms.

Leucippus’ biological theories

Leucippus’ theories on biology basically project his initial theory on atoms and the atomic structure of the matter. Leucippus claimed that “feeling” and the “intellect” come from the outside, whereas nothing is true or



Figure 1. Leucippus (probably 480-420 BC). Public domain. Obtained by <http://www.de-bric-et-de-broc.com/dico.html>.

understandable “except for the basic elements, which are: atoms and void” [17]. Everything “happens according to imagination and opinion,” which according to Leucippus seem to function as “paddles immersed in water” [18].

Vision, according to Leucippus, starts as a mirror image of the object in the pupil of the eye [19]. The various color tints emanate from the juxtaposition between the various colorful atoms [17]. This is also our present view about vision.

As for sleep, Leucippus argues that it “occurs when the output of thin elements is greater than the inflow of mental heat.”

Finally, the sperm is an extract of the soul, while gender differentiation is due to “variation of the molecules of the genitals” [20]. Today, it is known that genes carried by the Y chromosome are responsible for gender differentiation!

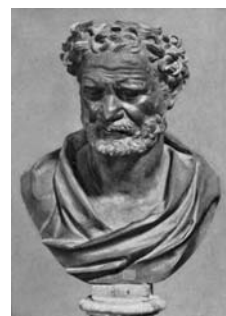


Figure 2. Democritus (460-370 BC). Bust of Democritus, Naples National Museum, Italy.

Democritus

The life of Democritus

Democritus was born in Avdera, during either the 70th Olympiad (500-497 B.C.), according to Eusebius of Caesarea [21], or the 80th Olympiad (460-457 B.C.), according to Apollodorus of Athens as reported by Diogenes Laertius [22]. The name of his father, according to Laertius, was Igitratos, Athinokritos, or Damasippos [18]. He was a very wealthy man. This enabled him to be well educated. Democritus was a student of Anaxagoras [23] and according to Herodotus, he also studied under Chaldean magicians¹.

According to Demetrius and Antisthenes, Democritus traveled to many countries. In Egypt he learned the sacred geometry of the Egyptians, and in India and

¹ Chaldeans was an Assyrian tribe who lived in the marshy lands in the far south of Mesopotamia, at the head of the Persian Gulf.

Ethiopia he met the Gymnosophists² [24]. It is reasonable to suppose that he stayed for some time in the Greek city of Teo in Ionia, Asia Minor. In Ephesus, Democritus probably met Leucippus, his former teacher.

Laertius mentions that Democritus also visited Athens, which seems probable since the city of Avdera was commercially connected with the homeland of Socrates and Plato. Democritus traveled in anonymity to Athens, and found that no one considered him as a well-known philosopher. He apparently encountered Socrates, who also did not seem to recognize him [25]. Not satisfied with the Athenians, he did not try to present his work there. He completed his visits within and outside the so called Greek world at that time and returned to Avdera. Avdera was then very prosperous city, since it had not been affected by either political conflicts or by the Peloponnesian War.

It is very likely that Democritus established a new school of philosophy. According to Laertius, in order to exercise his intellect, Democritus often lived isolated and in desolation in the country, sometimes close to cemeteries [26]. Because he had spent all his fortune during his travels, upon returning home he risked being condemned to death, as was the law in Avdera to condemn those who had spent all their inherited fortune. Democritus then read to the public his major work, *The Great World System*. His fellow citizens were moved by what they had heard and excused him [26]. Democritus also saved his city from starvation by giving appropriate instructions during the summer. As Clement says: "Democritus by observing certain stars predicted that much rain would fall. Those who complied with his instructions secured their harvest, while those who did not lost their crops because of the heavy unexpected rain" [27]. His fellow citizens honored him in many ways. They gave him five hundred talanta, erected cupreous statues of him and, after his death, buried him on public expense [28].

Over 60 treatises have been attributed to Democritus, which are organized in tetralogies. Unfortunately, we only know the titles of them, as recorded by Diogenes Laertius. We also know of almost three hundred extracts because they are incorporated or referred to in the texts of various ancient writers. However, even ancient writers wondered why Democritus' works had been lost. Various hypotheses had been formulated, including one that Plato wished to burn Democritus' works, but his students prevented him of doing [29].

Democritus probably died between 370 and 360 BC. When Democritus was very old and ready to die, his sister who was a priestess was depressed because if he was to die during the feast of Thesmophoria she would not be allowed to fulfill her religious duties to the goddess. Democritus told her not to worry but to bring him loafs of warm bread every morning. She did so, and he kept them close to his nose, while breathing. When the three-days of the religious feast were over, Democritus died[30]. His age at the time of his death is disputed. Diodorus of Sicily mentions that he died at the age of 90 [31], In *Chronicon of Paschale*³ it is referred

that he died at the age of 100 [32], Lucian mentions, at the age of 104 [33], and Censorinus, at the age of 108 [34].

The completion of the atomic theory by Democritus

As mentioned before, Democritus adopted the theories of his teacher, Leucippus concerning atoms and the void. He clarified the relationship between atoms and void: "The beginning of all things is the atom and the void, whereas everything else is simple belief. The worlds are innumerable; they are born and die without cessation. *Nothing is born of the non-being or decays into non-being*, whereas atoms are infinite in size and in number. They move in the form of a vortex within the whole, and thus they create all things that have shape such as: fire, water, air and ground by the process of conjunction. The four above basic constituents are compounds of established atoms. Atoms, due to their solid nature, are unchanged and unaltered" [35].

Democritus completed the atomic theory, which may be summarized under five points: a) every part or substance of our body is composed of atoms, which are invisible parts of matter that cannot be separated further. Democritus claimed that the division of matter is not indefinite and stops at the level of atoms. The word "atom" itself implies its meaning. It is derived from the privative "a" and the verb "τέμνω", meaning *incise* or cut. Thus the word atom means "what cannot be cut further." According to Democritus, any further division of the atoms would lead to complete decomposition so that it would be then impossible to reassemble the matter. If matter can be reassembled, new forms of matter will be produced out of simpler atoms, whilst decomposition and recombination of atoms is interchangeable. According to Democritus, this reversibility determines the threshold of segmentation, since it is the constant reference point of minimal particles from which we can compose visible matter. b) Empty space exists between the atoms [36]. Given that atoms are composed of the same substance as matter, all changes in matter are the result of atoms' movements. The space in which atoms move is the void. c) The composition of the atoms is absolutely solid: Void cannot exist inside the atom; otherwise the atom would be susceptible to changes from outside and could decompose and no longer be an atom. d) All atoms are homogeneous, without internal structure. e) Atoms are diverse in size and shape [37]. The above a), b) and c) are basically Leucippus' theories, Democritus added the last two points as for the homogeneity and the atom space diversity.

Views of Democritus in Biology and Medicine

Many ancient authors refer to Democritus. In Souda, a massive 10th century Byzantine encyclopedia of the ancient Mediterranean world, formerly attributed to an author called Suidas, mentioned that Hippocrates was a student of his father, of Irodicos, of Gorgias of Leonteion and also a student of Democritus [38].

Diogenes Laertius refers to a meeting of Democritus with Hippocrates in Avdera, when Hippocrates came to Avdera to treat Democritus: "Democritus asked for some

² Gymnosophists is the name (meaning 'naked philosophers') given by the Greeks to certain Indian philosophers who pursued ascetism to the point regarding food and clothing as detrimental to purity of thought.

³Chronicon Paschale (the Paschal Chronicle, also Chronicum Alexandrinum or Constantinopolitanum, or Fasti Siculi) is the conventional name of a 7th-century byzantine universal chronicle of the world. its name comes from its system of christian chronology based on the paschal

cycle; its greek author named it 'epitome of the ages from adam the first man to the 20th year of the reign of the most august heraclius'

milk; he looked at the milk and said that it was from a black goat that gave birth for the first time. Hippocrates appreciated this accurate statement. Democritus welcomed a girl, that also came with Hippocrates from the island of Ko. On the first day he greeted her by: "Hello, girl!" The next day called her, "Hello, woman!" Indeed, the previous night the girl had lost her virginity" [39].

Democritus said that the abiotic⁴ genesis of living creatures and of the whole world emanates from "muddy and murky elements, which created a sediment because of their weight, along with liquid elements. As this mass twirled without ceasing around itself, it gradually condensed, and the liquid formed the sea while the most solid matter created the earth, which was at first still muddy and very soft" [40]. Human beings emerged from the earth spontaneously [41]. To that point, Democritus erroneously connects the genesis of living and non-living things from abiotic matter, a theory that was finally brought down by Louis Pasteur.

The birth of children was then imposed by Nature [42], and fertilization is a slight collision of the female and male sperm [43]. Semen consists of the main body parts, such as bones, flesh and nerves [44], whereas females are actively involved in fertilization, not being just receptors, and also produce a type of sperm. This view is an established knowledge nowadays, although it was temporarily abandoned in the post-Democritus era [45]. Intrauterine sex is not dependent on heat and coldness, but on the prevalence of either the male or the female sperm. The predominance of the paternal or the maternal progeny is responsible for the similarity of the offspring to the father or to the mother. The embryo inside the uterus is nourished through his mouth and after birth child brings his or her mouth to the breast, since inside the uterus there are various nipples and mouths from which embryos are fed (meaning the papils of the placenta). At this point, Aristotle disagrees with Democritus, claiming that the fetal vein is connected with the uterus like roots in the ground, and from those veins the embryo is fed (probably meaning the umbilical cord) [46]. Democritus believed that when the uterus accepts and envelopes the entering semen, menstruation ceases. The umbilical cord is the first structure formed in the womb, and resembles an anchor or the stalk of a growing fruit that protects the fetus from turmoil and from upward or downward movements [47]. According to Democritus teratogenesis is the cause of a non-synchronous meeting of two sperms in the uterus, arriving there at different moments [48]. Premature miscarriage is due to hot southern wind, because under its effect, a pregnant uterus relaxes and expands, and the fetus moves here and there; when the uterus gets heated, the fetus glides easily and miscarriage is caused [49].

Democritus uses the word *πολύγονα*⁵ for cases of multiple pregnancies, such as in pigs and dogs. Females of such animals, he says, have more than one uterus for the suitable accommodation of the sperm. During the reproduction season, they copulate not just once, but two and three times successively, so that the semen fills all these cavities. Mules do not give birth because their uterus does not resemble other animals' uteruses, due to the animal's unnatural origin. Democritus argues that this abnormal behavior of mules is a result of human intervention; Humans force the donkey to mate with a

mare, whereas the natural is that members of the same species to mate with their counterparts [50].

Based on the writings of Diogenes Laertius, we know that Democritus wrote at least five medical treatises: *Prognosis*, *On Diet*, *Medical Judgment*, *Causes Concerning Appropriate and Inappropriate Occasions*, *On Fever*, and *Coughing Sicknesses* [51].

According to Democritus, medicine cures the illnesses of the body, whereas wisdom relieves the soul from all its passions [52]. In his treatise *On Diet*, Democritus claims that for those who abstain from food, the night is long. Occasional behavior offers a rich table full of various foods, whereas prudence offers a table with all the necessary types of food only [53].

Democritus' views on human health in general are extremely interesting. For example, he considers day sleeping as harmful, since it leads to deteriorated fitness, mental disorders and indolence [54].

Democritus also supports taking the middle way in all human actions. He believes that those people who tend to exaggerate become traitors of their health [55], because all those who take pleasure in the delights coming from the stomach do not know the appropriate time to eat, to drink or have sex; they are prone to abuses and eventually wear themselves out [56]. Therefore, according to Democritus, the basic cause of disruption to human health is human behavior [57]. Negligence, intoxication, voluptuousness, desire to win and envy are in general the felonies of the soul and begetters of illnesses [58].

In addition, in his treatise *On Fevers*, Democritus claims that inflammation is causing an excess of phlegm, one of the four humors of human body according to the Hippocratic theory [59].

As far as cancer is concerned, he claims that, along with ulcers, is among the worst of diseases [60].

Zoology

Zoology holds an important place in Democritus' works. He studied the development of the horn of the deer, the castrated oxen [61] and the biology of fish. He believed that fish were fed not on salt water but on the sweet substances of the sea [62]. That the spider makes its web by using its excrement [63]. He also wrote about amphibians, saying that they could use both water and air [64]. He observed and hypothesized about the undulate movement of worms [63]; the black bones of the eagle [65]; the night vision of the owl, which he attributed to its eyes having too much fire and heat [66]; the cock's cackle at dawn [67]; and lions whose eyes are open during birth and during sleep [68].

According to Democritus, animals driven by their natural power can heal themselves faster than humans [69]. He believed that animals can teach much to humans. Men learned the art of weaving and embroidery by imitating the spider, the art of building by imitating swallows and the art of singing by imitating songbirds, swans and nightingales [70].

Idols, demons and the concept of a supreme power

For Democritus, the human body is a warehouse full of various and unbearable evils, since all the diseases come from it, though it also contains the power to heal. Most people do not know this and, for that reason, they pray to the Gods for their good health. Death comes from an excess of perspiration of the hot and of the aesthetic

⁴ Abiotic, meaning the genesis from non-living things

⁵ meaning multiple births

matter of different parts of our body, but not from all parts simultaneously [71]. In order to avoid decomposition of the body in the afterlife, Democritus recommends its maintenance in honey [72].

Air is also full of idols [i.e., demons-demonia, *δαίμονια*] [73], which penetrate the human body through its pores, causing dreams on their way to the upper parts of the body [74]. Dreams, he says in effect, are the result of idols (demonia) projecting in the mind [75]. These idols may be either good or evil, revealing the future to human beings, and because they appear, people believe in the existence of God [74, 76].

According to Democritus, God is a larger spherical atom made of fire [77]. God can attain material forms, but Democritus attributes the idea of a god, in addition to various dreams, to the fear that humans feel before the powers of Nature. He says that people naturally stare at the sky when various phenomena, such as lightning, thunder, the movement of stars, or the eclipses of sun and moon occur. They experience terror as they witness such phenomena, and so they attribute such events to Gods [78].

Physiology and Cognitive Psychology

The main interests of Democritus, however, are in the fields of Physiology and Psychology, particularly cognitive psychology and consciousness. Several extracts from these works have survived in the works of other philosophers [79]. He recognizes that arteries have their own movement, naming that movement: *φλεβοπαλίην* (pulse of veins) [80].

Democritus also theorized similar views as of Leucippus about knowledge, which he says, emanates from two sources: the senses and the mind. The first type of knowledge is based on the sense, he calls *genuine* or *legal knowledge*, because it is considered to be reliable, whereas the second one is called *dark* or *illegitimate*, stripping knowledge of the ability to infallibly discern, genuine truth [81]. For this reason, Democritus believed that colors and the taste of sweet and bitter are conventional truths since the only real truth lies within the basic structure of matter that we feel [82]. Hot or cold, sweet or bitter, acid or grumpy exist because of our ability to discern between various aesthetic properties related to distance, to the constitution of our body and our diathesis [83a]. For the sensation of various tastes, Democritus believes that is based on the effect of atoms of different shapes and angles diffusing in different ways into the human body [83b-e], while Theophrastus disagrees [83f]. All aesthetic attributes are produced by the collision of atoms [84].

Theophrastus criticized Democritus' ideas about the senses [85a]. According to Democritus, the ability to see the picture of an object, is the result of an emission [85b], just like the imprint that we make when touching a candle [85c]. On this point, Theophrastus asks the crucial question, if the idol of an object is impressed in air as the imprint on a candle, why does the idol not become transparent? According to Theophrastus, first of all it is impossible for a picture to be created as an imprint by an object that stands opposite to the observer, since the shape and characters of an imprint can only be visible if we see it from its back. A second question posed by Theophrastus is how we can see most of the objects in the air [85d] and how we can see each other, based on the theories of Democritus. Democritus accepted only four basic colors, white, black, red and green, consisting of atoms of different shapes [85e,f]; the rest of them are

the result of mixture of the basic colors [85g-i]. Theophrastus, questioned how black color was formed [85j].

The sense of audition, according to Democritus, comes from the movement of particles of air in the void and the entry of that air into the body. Voice is created when the air gets condensed [85k]. Theophrastus also considers unreasonable Democritus' theory that sound enters all over the body [85l]. Here Democritus is right, not Theophrastus. According to Theophrastus, Democritus claims the same for all the senses [85m]. Democritus believed that the whole body is participated by vision and audition, and claims that ears and eyes are simple receivers, a theory consistent with that of the participation of atoms and void in the formation of inorganic and organic matter.

The body is very cold or very warm, the mind is altered. In this way, it is obvious that consciousness as well as senses and thought are subject to changes [85n]. The experience of weight, of heavy and light objects, is not dependent on the size of the objects but on the void that these contain [85o]. In a similar way hard objects are denser than soft objects [85p].

About the Soul

The theory Democritus expounded about the human soul is considered to be an extension of his theory about senses [86]. Soul is one of the first and indivisible things, capable of causing movement due to its shape and the small size of its particles. The human soul moves the body by necessity- a possible explanation for the spontaneous automatic natural movements [87]. Soul exists within the body in two basic forms: a) reason, which originates from the chest, and b) non-reason, which is scattered all around the human body. Both forms, however, are perishable, as they are co-consumed along with the decaying body [88,89]. The soul is a "kind of fire" consisting of spheroid atoms which can easily "penetrate everywhere, as they move, and can put in motion the rest of the atoms of the body. The soul provides movement for the living creatures". Respiration is the sign of life. [90]. (*Δημόκριτος μὲν πυρ τι καὶ θερμὸν φησὶν αὐτὴν εἶναι [τὴν ψυχὴν] ἀπειρώως γὰρ ὄντων σχημάτων καὶ ατόμων [τὰ σφαιροειδῆ πυρ καὶ ψυχὴν λέγει οἷον ἐν τῷ αἵρι τὰ καλούμενα ζύσματα α φαίνεται ἐν ταῖς δια τῶν θυρίδων ἀκτίσι, ὠν.....: τούτων δὲ τὰ σφαιροειδῆ ψυχὴν, δια το μάλιστα διὰ παντός δύνασθαι διαδύνειν τοὺς τοιοῦτους ρυσμούς καὶ κινεῖν τὰ λοιπὰ κοινούμενα καὶ αὐτά, ὑπολαμβάνοντες τὴν ψυχὴν εἶναι το παρέχον τοῖς ζώοις τὴν κίνησιν. Διὸ καὶ τοῦ ζῆν ὄρον εἶναι τὴν ἀναπνοήν*). Respiration is essential for sustaining life because the restless atoms of the surrounding environment enter the body and therefore block the ejection of useful elements [90].

Other than the theory about the soul's property of movement, Democritus' ideas about soul and heat are identical. Both exist in abundance in the air, and they enter the body through inhalation, substituting what exhalation removes. On the concept of an imbalance between inhalation and exhalation, Democritus will build his theory about death. Death is the result of the exit of spherical atoms comprising mind and soul from the body, because the exterior environment exerts pressure on the body, overtaking or extinguishing natural body movements (a state like cardiac collapse) [91].

In conclusion, some of the invaluable philosophical doctrines of both Leucippus and Democritus presented here have not been well known up today. The most

important work of the atomic philosophers lies mainly on the basic structure of all living and all material things consisting of indivisible particles, the atoms, and void. In our days, the atom is still considered to be a basic unit of the matter, and is in constant movement. Of course now the atom has been split and fused. Mathematics, biology, medicine, physics, meteorology, geology, astronomy, ethics, religion and metaphysics were also studied by Leucippus and Democritus. It is of note that the theory of the genesis of the universe by the atomic philosophers is quite close to what it is now widely accepted; (infinite mass of the initial form of the universe -'Big Bang theory'). Color vision, fertilization, were studied perhaps by examining anatomical specimens of men and animals. The theories of Leucippus and Democritus about the mind and soul are still under discussion. *This overall, wide variety of knowledge concentrated in only one man demonstrates the ancient Greek model for "education" Παιδεία, a word which implies character molding, culture and basic education, a totally different concept in our days. This type of general education may benefit our era, if we choose to combine technology with humanistic and biological studies.*

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