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Atomism in Greek Philosophy*

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The concept of atom, "indivisible particle", stems from a speculative answer of Greek philosophers *Leucippus* and *Democritus* to the paradoxical concept of Being as proposed by *Parmenides*. The atomic theory was further elaborated by *Epicurus*, who gave new answer to the questions concerning the problem of movement and indivisibility of atoms. The concept of atom was criticized by *Aristotle*, who denied the real existence of empty space (void), and claimed that matter was infinitely divisible. *Plato*, however, viewed "atoms" as regular geometrical solids constructed from immaterial elements – triangles.

Along with the overview of development of atomic theory among the Greeks, the paper deals with the influences of Greek philosophy on the development of dynamic atomism in the 18th century, especially the theory of Croatian scientist *Josip Ruđer Bošković*. The reflections of Greek atomism may be found in modern mechanistic explanation of chemical and physical problems (*Democritus*), stoichiometric concept of atom (*Epicurus*), quantum-chemical and stereochemical models (*Plato*), and models based on molecular volumes (*Leucippus*). Atomic theory proposed by *J. R. Bošković* has, however, its counterpart in force-field methods of theoretical chemistry.

Key words: *Democritus, Leucippus, Plato, Bošković, molecular volumes, quantum chemistry*

We know nothing truly, for the truth
lies hidden in the depth
(Democritus)

Introduction

It is popularly assumed that atomic hypothesis stems from logical impossibility of infinite divisibility of matter, namely that *Democritus* (or *Leucippus*) derived his "indivisible one" (*a-tomon*) by such a straight philosophical reasoning. But if it is true, how is it possible to oppose the very existence of atoms by the same argument (*Aristotle*) – that it is impossible to comprehend infinitely small particle?

The answer to the question may be found in a book written almost two thousand years after the speculations of the two Greeks. In the *Critique of Pure Reason Immanuel Kant* stated that there were antinomies of the mind, meaning that some theses (and well as their antitheses) cannot be proved or disproved in any way of speculative thinking – both YES or NO answers are seemingly acceptable and, at the same time, disprovable.[1] These antinomies** (the term meant originally contradictory legal act) stem from the very nature of human thinking: in an effort to comprehend the whole, mind is being lost in the realm which is not of its own, for the mind may deal only with the concepts of which our senses have or might have *real experience*. (As the whole cannot be reached by senses, or experimentally – to say it in a modern scientific language – mind is not capable to form any non-contradictory concept of totality of beings.) The strive to learn about Nature by using the concepts obtained by pure speculation (i. e. concepts of pure reason), without the link to experience, said Kant, is futile, not because of our feeble intellectual abilities but because of the very nature of human comprehension. The concept of atom, as we will see later, originated not from free philosophical speculations, but was derived as a direct opposition to them. In the well-known Democritus's fragment, senses speak to the mind: "Wretched Mind, from us you are taking the evidence by which you would overthrow us? Our overthrow is you own downfall."[2] This sentence points to the central thesis of Kant's philosophy, that sensory perception (*Sinnlichkeit*) furnishes the mind (*Verstand*) with the material needed to form theoretically useful (= experience related) concepts; or to say it in Kant's own words, concepts without senses are empty, and senses without concepts are blind.

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**There are four such antinomies, "collisions of transcendental ideas in the antinomy of pure reason". Besides the second antinomy, "every non-simple substance is composed of elementary parts" (antithesis: "there is nothing simple in the world"), there are antinomy concerning space and time (space and time are infinite/space and time are finite), cause (everything is causally related/it must be an additional cause based on freedom), and finally on the totality of the world, i. e. on the existence of Supreme Being, the God (there is a being of necessary existence/there in no such a being). It is impossible to find a non-contradictory answer to these questions: discussions cease when one of the opponents has left arena, not because he has turned his mind. As the Aristotle's argument came after Democritus's, it is quite natural that atomic hypothesis was not very popular in the proceeding centuries.

The second argument against the popular assumption at the beginning of this paper is doxographic. Although the sentences from Democritus's books are collected among the fragments of "Presocratic philosophers", what is among the philosophers at the first place, cosmological period of Greek philosophy, the full truth is it is so only because all original writings of this thinker has been lost. Despite the fact that Democritus wrote about 60 books (ranging from natural science to mathematics, ethics, music, art, and phylology), his school in native Abdera (Ionia) did not persist, so there had been no follower to conserve his learning by rewriting his manuscripts. At the time when many philosophical schools were starting to flourish in Athens, a provincial philosopher had little chance for success. "I came to Athens and no one knew me",[3] says Democritus in one of his thoughts of doubtful originality. But was Democritus visiting or not visiting Athens, the sentence tells us very clearly that Athenians did not care much about "foreign" philosophers and their philosophy, much less if they were coming from Abdera, the Ionian city "well-known" for the foolishness and stubborness of its inhabitants.

From the chronological point of view *Democritus* (460–385) was contemporarian of *Socrates* and *Plato*, and *Aristotle* was born only a year after his death. If we accept the standard dividing of Greek philosophy to cosmological (600–450), anthropological (450–400), and systematic period (400–322), *Democritus* should not be in any way taken as "cosmologist". His philosophy deals, naturally, with cosmological (i. e. physical) problems, but his atomic hypothesis furnishes the answers not only to the questions concerning the beginning of the world and the nature of things, but also to the question on nature of sensual qualities, physiology of hearing and vision, and – last but not the least – to the ethical problems, which were elaborated in dozens "seeds of wisdom". For his thoughts, written mostly in a gay and humorous manner ("Do not let a women practice reasoned argument; that is frightful",[4] "Man enjoy scratching themselves – they get the same pleasure as those who are having sexual intercourse"[5]), *Democritus* was called "the laughing philosopher".

There are other reasons why it is correct to place *Democritus* among the philosophers of the systematic period of *Plato* and *Aristotle*. Although contribution of his teacher *Leucippus* (490 – ?) to the final formulation of atomic theory is dubious, there is a little doubt that idea of the existence of atoms originated from Leucippus, not from *Democritus*. But the most powerful argument in favour of regarding Democritus's philosophy as equivalent to the systems of *Plato* and *Aristotle* is the fact, that it has stemmed from the same questions which moved latter thinkers to establish their philosophical systems. The principal question was about the nature of reality, or, to say it more clearly, Democritus's philosophy has been direct answer to the paradoxical theses delivered by the adepts of School of Elea, in southern Italy.

The ultimate stuff of Nature

There are two theses which are trying to explain the origin of Greek philosophy. According to the first opinion,[6] philosophy of the Greeks has to be regarded as a rationalization of myths, i. e. as a sort of rational elaboration of religious belivings (much like a medieval theology). The second thesis sees, however, the Greek philosophy as a direct opposition to the irrational mythological beliefs, as a rational critique of mythology.[7] Helenic mythology has not been in any way exceptional among the mythologies of these times, and the cosmological myths in particular are much less endowed with phantasy than myths of Egyptians, and have less resemblance to modern cosmological theories than the myths of Indians. It was the science which had run Greeks to the paths of rational philosophy, moving them to do the unique achievement in the history of mankind. Greeks were the nation of sailors, merchants, and more than everything else – the nation of lawyers and politicians; every adult male Greek had been trained for rational argument (*logos*), because of his skill to defend his arguments in public depended his wealth and position, and often his very life.* It was also usual for Greek philosophers to be ateists, at least they did not share official religious believing (Xenophanes was known as "condemmner of Homer's lies", Socrates was sentenced for "making his own gods", and "demiurg" of Plato along with "unmovable mover" of Aristotle have very little in common with anthropomorphic gods of Greek mythology).

But opposed as the two theses could be, only by accepting both of them it is possible to understand the rise and nature of Greek wisdom. Rational thinking coined at market and in court has been the germ of Greek philosophy, but its foundation is, doubtless, mythology. For the first question, which originated in Greek philosophy, "Which is the ultimate stuff of Nature?", was essentially the same as "Which is the nature of Chaos?" In all the philosophy of cosmological period lays the fundamental believing, that there must be something from which all other is composed, or better to say from which all other is originated.

The question, whether Nature is *composed of* or *originated from* the first substance (*arhē*), is essential. Having explained why the first philosopher of cosmological period, *Thales* of Miletus (624–546) had chosen water as the ultimate substance, *Aristotle* said it was so because all animate beings were *generated* from water.[8] Water for *Thales* has obviously been *generating principle*, a material forefather of all beings, as Chaos is in mythology. As Greeks comprehended Nature as a wholesome being that was changing itself by its own powers (*natura naturans* – fabricating, generating Nature – to say it in scholastic terminology), they did not at first realized the problem how to explain the change in the world about them. Hylozoism, believing that everything is animate (but beings differ in the level of complexity), has been the commonplace of Greek philosophy. For Greeks the living meant simply to be a cause of movement by itself; Thales assumed magnetite to be an animate being (since it was capable to attract iron),[9] and even Plato thought the sun being alive since it moved spontaneously through the heavens.

*The legal procedure was very simple among the Greeks. The accuser was speaking until water filled the clepsydra, proposing the penalty at the end of his talk. After that the accused was speaking for the same time trying to persuade the jury in his innocence. The jury, made up at *hoc* by the public at agora, has voted in favour or disfavour of the accused. The accused, if found guilty, had the right to speak during the yet one water--filling to pray for less heavy penalty, and the second vote finished the sue.

But if the ultimate substance (*arhē*) is water, which kind of water it is? There are, of course, many kinds of water. The first substance has to be of simple qualities, for it has to share properties with all substances, but should not be equal to any of them. The same problem appeared among the alchemists in the Middle Ages, who were proposing three roots (*tria prima*) of matter – *mercurius* (mercury), *sulphurus* (sulfur) and *sal* (salt) – but they were not to be identified with any of the respective chemicals; the "roots" are by their very nature *principles* (*mercurius* is the principle of liquefaction, *sulphurus* of dryness and combustion, and *sal* of solubility), and were properly called *philosophical* (*i.* e. alchemical or scientific) mercury, sulfur and salt.

The problem which faced the first philosophers was not fully understood till our times: *essence* (quality, appearance, or concept) of thing has to be ragarded separately of its *existence*, the fact that it *is*. But Thales's disciple and follower in the School of Miletus, *Anaximander* (610–546) was close to this reasoning for he named the first substance, *arhē*, as *apeiron* (unlimited – indefinite and infinite). Anaximander's "unlimited" cannot be identified with air, water, or any perceptible substance.[10] Traditional Greek elements (water, earth, air, and fire) are merely forms of *apeiron*, which is the first nature (*fisis*) of everything. *Apeiron* is only a possibility, potential existence of things, a concept very close to *hyle* (matter, stuff, material), as proposed by *Aristotle*. For *Hegel apeiron* is "absolute continuity of matter", "matter in general".[11]

Such a philosophical reasoning led to the most strange theory of matter, which originated in the southern Italy, in Elea. For the founder of the School of Elea, *Xenophanes* (580–485), all is One (*to on*), and the One is identical with God.[12] The One is alive, in the sense it can see, hear, and think, but has nothing "in common with man",[13] which means that One is God, but not an anthropomorphic god.[14] Such a pantheistic concept of Nature was further modified by his pupil and follower *Parmenides* (540–480). He defined the One as finite (of limited size), spherical (isotropical), motionless (there are no real changes in Nature), and as continuous plenum ("it has no place in itself"), assuming that there is no void in Nature.[15] But, if the ultimate substance is "motionless" (unchangeable), how the changes in Nature occur?

Parmenides proposed the existence of two truths: the first originated from the senses, the second from the mind. The truth of lower grade, based on sensory perception, explains the changes by proposing interactions of two elements – fire and earth – and their corresponding principles – hot and cold,[16] but is in no way connected with the higher truth, which stems from rational argument (mind). Such a philosophy is, to quote Aristotle, "very close to madness".[17]

As strange the theory of matter as could be, Parmenides's teaching had the tremendous influence on further development of Greek philosophy. It is not crucial that his theory led to a number of paradoxes stemming from collision of logical thinking with the experience furnished by senses; the fact of utmost importance is that Eleatic philosophy ended in the splitting of truth, one part of it belonging to senses and the other to the mind. All further efforts of Greek philosophy went to fill the gap which had opened in "reality". Atomic theory is, from a historical point of view, only a trying to resolve the Parmenides's paradox.

Atomic solution

There are not many thoughts of Democritus which came to us unchanged. One of them is crucial not only for our understanding of his philosophy, but also for deeper insight into all non-Aristotelian theories in physics, of which modern science is build:

*Sweet is **by convention** and bitter is by convention, hot by convention, cold by convention, colour by convention, **in truth** there are but atoms and the void.*[18]

Democritus, like *Parmenides*, accepts that there are two kinds of knowledge, knowledge obtainable by senses ("by convention"), and the true knowledge ("atoms and the void"), obtainable by speculative reasoning. But these two "truths" are not more mutually unconnected, as in Eleatic philosophy. In spite of assumption that sensible qualities led only to "dark knowledge", these qualities can be derived directly from the "true knowledge", by explaining them by the movement of atoms. In this respect, to use the terminology of Renaissance philosophers, properties of atoms are **primary qualities**, and properties of perceptible things are **secondary qualities** of the same physical reality. The primary qualities of matter (atoms) are essentially different from secondary qualities (perceptible things), but in spite of this, the two "realities" are **causally** connected.

The second revolutionary concept which stems from the atomic theory is void, empty space. "*Leukippos* [*Leucippus*] was the first philosopher to affirm, with a full consciousness of what he was doing, the existence of empty space", wrote *John Burnet*. "The Pythagorean void has been more or less identified with 'air', but the void of Leukippos was really a vacuum."[19] The "discovery" of vacuum cannot be overrated; its existence enabled atomists to find a theoretical basis for change and, at the same time, to fulfill the Parmenides's claim for singularity and homogeneity of the ultimate nature of things. To Parmenides the "One" is Being, and void, as non-Being, is simply non-existent (because void, being nothing, is unconceivable). According to atomists, atoms compose the Being, but non-Being, void, enables their movement and very existence. *Hegel* said laconically that atom is "absolute punctuality", and void is "absolute continuity".[11] The thesis and antithesis of the second Kant's anitinomy were found united in a sound physical theory.

Leucippus, to say it allegorically, crushed Parmenides's sphere and dispersed its parts in the void. For speculative, purely philosophical aims it was enough, but it has to be noted that Greeks had not seen boundary between philosophy (in a modern sense) and science. Science and philosophy were not only inseparable but also indistinguishable. (To *Aristotle*, the first philosophy – methaphysics – was merely a part of theoretical philosophy; other parts were physics and mathematics. Other philosophers did not make even such a distinction.) Atomists, as "physicists", proposed of course the properties of "indivisible ones" – atoms:

They [*Leucippus and Democritus*] *say that differences* [*among the atoms*] *are three in number – **shape, order, and position**. For they say that beings* [*atoms*] *differ only by 'rhythm', 'contact' and 'mode' – where 'rhythm' is shape, contact is order, and mode is position. The letter A differ*

from N in shape, AN differ from NA in order, and N differs from Z in position.[20]

This quotation, for which we may thank Aristotle, led some chemists to pronounce *Democritus* as a herald of isomer theory[21] (for isomers are differentiated by **order** and **positions** of atoms), but Democritus's atoms have also four inner properties: size, shape, weight (density), and softness.[22] Movement of atoms were explained by their differences (smaller atoms were moving faster), and their arrangement into perceptible bodies, was determined by their shape. ("He explains how the substances remain together in terms of the ways in which the bodies entangle with and grasp hold of one another; for some of them are uneven, some hooked, some convex, and other have innumerable other differences."[23])

Of course, atoms are indivisible. *Leucippus* and *Democritus* assumed that nothing smaller than atom could be conceived;[24] but in this statement lays a contradiction.

If atom has a shape it must be divisible. Even if it is absolutely isotropical and homogenous body (homogenous sphere) it must be divisible, at least mentally. Is an atom real (material, perceptible) entity or only a mental scheme? If it is material entity, it has to have sensual qualities as any material object has, and proposing its different level of existence ("in the mind") is therefore pointless. Were it a mental scheme, atom is a being of "absolute punctuality", in Hegelian sense, and it should have neither size nor shape.

Although *Leucippus* and *Democritus* introduced new concepts and problems (difference between primary and secondary qualities, relation between sensual and ideal reality, mechanistic explanation of natural phenomena), their original theory has been in its very essence contradictory.

Atoms of senses

The atomic theory reached its peak in the school founded in Athens by *Epicurus* of Samos (341–270). As many philosophers after *Socrates*, *Epicurus* was interesting himself mainly in ethics (teaching the doctrine of rational hedonism), and his philosophy, along with the philosophy of Stoics, was very popular among the Romans. As a radical materialist, *Epicurus* accepted atomic theory of *Leucippus* and *Democritus*, but recast it in a strictly mechanistic way. Atoms are not indivisible particles because their cutting cannot be conceived, but because there is no such a process in Nature. His follower and venerator, the Roman *Titus Lucretius Carus* (95 – 55) in the poem *De Rerum Natura* (On Nature), thoroughly exposed philosophy of *Epicurus*, naming the atoms as *corpora prima* (the first bodies) or *semina rerum* (seeds of the things).

Epicurus did not only provide an answer why atoms are indivisible, but proposed a new theory of change. According to *Democritus*, atoms are moving due to chaotic collisions (explanation close to the modern kinetic theory of gases), but Epicurus assumed atoms to be moving by their weight (like rain drops); there is unending shower of atoms in Nature. But, said *Lucretius*, was the fall only motion, no change would be possible for it was impossible for falling bodies to collide. (Interesting to note, Lucretius explicitely said that all atoms, irrespectively of their size, were falling by an equal speed since they were moving in the void. This hypothesis, which strongly opposed the dominant, Aristotelian theory of motion, has not been experimentally confirmed until the 16th century.) The ultimate cause of all changes in Nature, says Lucretius, is unpredictable horizontal movement of atoms, which gives, to say in a modern language, horizontal component of impulse. In this way to the strictly regular and determine natural process, a random, unpredictable event was introduced.

Critique

To the Greek and Roman philosophers atomism did not appear to be in any way exceptional: it was but one of many speculative answers to the question of ultimate reality. It was radically materialistic philosophy with ethical consequences reflected in rational hedonism of Epicurus; no wonder that the philosophers of the rivaling school, *Stoics*, strongly opposed it. *Cicero* regarded atomism as a narrow-minded and rough explanation for the immense diversity of natural phenomena and complexity of mental processes (soul).[25] The theory stating that everything could be reduced to the movement of indivisible and invisible particles, which keep each other with hooks and similar mechanical "devices", had to *Cicero* no more credibility than a fairy tale. From a scientific point of view, atomism had been only a vague hypothesis, since there was no experimental proof for their existence, less for their properties, and the connection of properties of "indivisible ones" with the properties of perceptible things, which was the core of atomic theory, had not been established even at the level of hypothesis.

The death blow to atomism came, however, from Aristotle. Thinking in lines with the future Kant's antinomy, Aristotle clearly stated that it was impossible to comprehend indivisible particle, because such a particle should be of zero size; perceptible beings should therefore be composed of nothing and the whole should be just an illusion.[24] It is also impossible to imagine a quantity composed of particles which lack any quantity. As a second argument against atomism Aristotle put the notion that the "pure" generation of things cannot be explained by rearrangement of atoms alone: "Pure generation and corruption are not due to the association and dissociation of particles, but the thing as a whole is coming over to another thing."[24,26] To the "naive" mechanistic theory, Aristotle counterpossed holistic view of Nature, which had been the central point of his philosophy.

The next weak point of atomism was the proposed existence of the empty space (vacuum, void). Atomism implicitly takes the space to have real existence, quite in lines with the future Newton's views of the "absolute, true and mathematical" (*absolutum, verum et mathematicum*) nature of "absolute", i. e. non-empirical, time and space. To this concept of time and space, known later as subsistence (necessary condition for existence of things), Aristotle opposed time and space as inherences (necessary consequences) of the earthy existence. Commencing from the Zeno's paradox about the arrow (arrow is not moving at all

because in every moment it stays still), Aristotle concluded that space and time had to be defined by "points", boundaries between things and events, but the points themselves were neither in space nor time, for the boundary by itself made space and time as an objective physical reality. In other words, space (place) without the object and time without events is a concept having no physical meaning.[27]

The existence of empty space is not necessary to explain movement, says Aristotle, since a body removes other body from its place[28] (validity of this argument depends, obviously, how time and space are defined). To the philosophic arguments Aristotle added the one which was purely "scientific": against the "evidence" for the existence of empty space – the volume of ash decreases after addition of water – Aristotle said that among the particles of ash there was not vacuum but air.[29]

Aristotle was undoubtedly the greatest Greek philosopher, if not the greatest philosopher of all times, and his arguments against the existence of atoms had never been seriously opposed on philosophical ground. The revival of atomism in the 17th century was due to new scientific discoveries, not to new philosophy.

Atoms of Plato

Among the many theories on the nature of matter in ancient Greece, there is one which has no direct connection to any of previous or future theories; from no theory it was derived neither it evolved to any other. This theory we are owing to Aristotle's teacher *Plato* (427 – 347), who exposed it in his "dialogue on natural science", *Timaeus*. Less than any other speculative answer to the ultimate nature of matter, Plato's theory is based on reasoned arguments; the dialogue has a form of a narrative, myth, and Plato did not give any other argument in favour of his speculation but the "argument" of beauty, which is earthly reflection of the supreme wisdom, perfection, and the goodness of the demiurg, the Creator.

Ultimate reality of matter are its forms. There are, traditionally, four elements (water, earth, air, and fire) and consequently each of the elements corresponds to one of four regular geometrical solids (known as Platonic bodies, Fig. 1). A strange mixture of associative and logical thinking connects geometrical forms with their material counterparts. "Earth" was proposed to have the form of cube for the cube is "the least moveable ... and plastic among the bodies", "fire" has the form of the tetrahedron since it has "the sharpest edges... and the smallest number of faces", and so forth.[30] But the four bodies are not the ultimate elements of which all matter is composed. It is easy to see that all Platonic bodies are constructed of rectangular and equilateral triangles. These triangles enabled Plato to develop the theory of "chemical changes" as well: one element was turning into other by rearrangement of elementary triangles. Thus the Platonic atoms are not indivisible, although they are regarded as the ultimate particles of matter.

Platonic elements should not be viewed as real water, earth, air, and fire, but rather as their components. Liquid water is mixture of "fire" and "water", which after the release of "fire" by cooling turns into "earth" by the process of congealation of particles. Gold is composed of the smallest and most homogenous particles of "water", and the substances like glass, tar and wax are supposedly made up of larger particles of "water" mixed with smaller particles of "earth".

Founding his philosophy on ideas, which were taken as reality, the ultimate nature of things, Plato missed to connect the ideas to perceptible things; therefore *chorism* ("splitting off") is the most general characteristic and major drawback of his philosophy. So it is with the theory of matter. Plato did not even try to expose how forms were "impressed" into matter, the nature of which was regarded as mysterious ("hard and dark"). But the reflection of matter as a pasive principle ("nurse of generation") connects Plato's philosophy with the archaic, mythical view of Nature: form is regarded as an active (heavenly, paternal) and matter as a passive (earthly, maternal) principle.

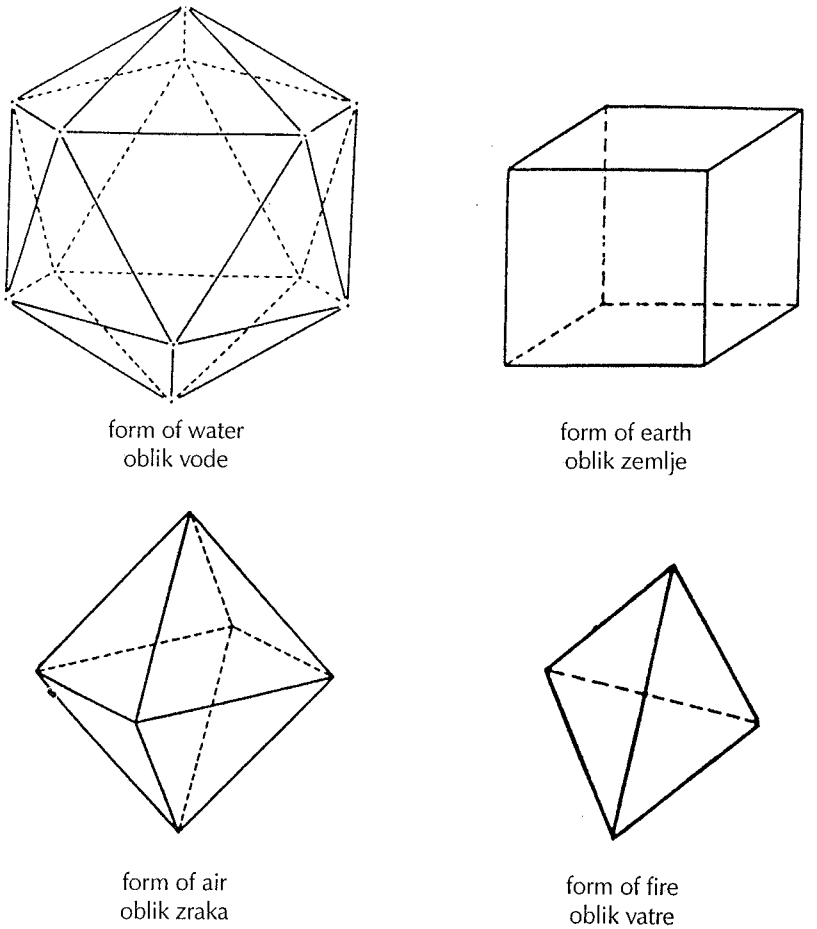

Fig. 1 – *Atoms of Plato: The four regular geometrical solids (Platonic bodies) correspond to four traditional elements, as their forms*

Slika 1 – *Platonovi atomi: četiri pravilna geometrijska tijela (Platonova tijela) odgovaraju četverima tradicionalnim elementima, kao njihove forme*

Reflexes

Matter is constituted of particles, separated by comparatively large distances; it is embedded in empty space. This notion goes back to Leucippus and Democritus, who lived in Abdera in the fifth century BC. This conception of particles and empty space is retained up today... and not only that, there is complete historical continuity also.[31]

These words of the eminent physicist of 20th century, *Erwin Schrödinger*, points to the basic concepts in atomic theory, which contemporary scientists share with the ancient Greek philosophers. But by one statement Schrödinger is in error: there is no "complete historical continuity" of atomism. Truth is that the last vestiges of atomism vanished in the first century with Titus Lucretius Carus, and through all the medieval centuries theory of matter was firmly grounded on Aristotle and Plotin's philosophy. Chemical reactions were viewed as qualitative changes of "forms" of "matter", quite in accord with Aristotle's physics founded on the theory of "four causes": matter (*hyle*), form (*morfē*), effective cause (*he arhē tēs kinēsēs*, cause of movement, change) and final purpose (*télos*). Even alchemists' dream of transmutation of base metals into gold can be traced back to Aristotle's philosophy: idea that the matter could be deprived of the form to obtain *materia prima* is a diserstion from original Aristotelian philosophy, steming from assumption that form and matter are really separable. (Aristotle plainly differentiated "first" and "second" matter: only the latter is a real physical substance, the former is merely an abstraction – possibility of change.)

The revival came with Renaissance, when – in the humanistic movement – the books of Greek philosophers were searched for a long-forgotten truth.[32] But the first notion of atoms (*particula strita*) appeared in the writtings of French philosopher *Descartes* c. 1630. His compatriot *Pierre Gassendi* introduced the concept of atom (*atom, corpuscula*) and molecule (*molecula, minima concretincula, corpuscula*) in 1658. The introduction of atom into chemistry is, however, due to *Robert Boyle*, who in 1661 founded the modern chemical theory, stating that indivisible atoms (*minima*, or: *prima, naturalia*) bind to form molecules (cluster, primitive cluster, *prima mixtura*).[33] From the philosophycal point of view it might be said that Boyle revived Epicurean atomism, since he assumed indivisibility of atom to be merely an experimentally established fact. From this strict empirical concept of atom arised a historical paradox that Boyle, although, has been credited for the modern definition of chemical element, nevertheless believed in transmutation of the elements (because he did not rule out the theoretical possibility of *opus magnum*).[34] In these lines goes also atomism of John Dalton (1810), who proposed that all atoms, "simple elementary particles", of particular chemical element had constant mass.[35]

But there was another way to discuss the nature of "indivisible ones". Beside the "chemical" approach to atomic theory, which viewed atoms merely as participants in chemical changes, there were also physical approaches, which regarded atoms as particles in mutual interactions (dynamic atomism). In this line of thinking the theory of Croatian scientist *Ruđer Josip Bošković* is of foremost importance.[36] In the *Theory of Natural Philosophy* he stated:

According to my opinion the first material elements are entirely indivisible and inextensive [dimensionless] points, which are thus dispersed in infinite void that any two of them, mutually spaced by an interval, which could be indifinitely increased or decreased, but cannot be entirelly anihillated without the compenetration of those points; for I do not permit the possibility of their continuous arrangement [continuity], but judge to be undoubtedly certain if distance between two material points is null, it is necessary that both points must occupy entirely the same space according to vulgar concept [i. e. place, empirical space]; and then should happen the real and absolute compenetration.[37]

Bošković thus proposed that atoms were indivisible and **dimensionless** points (*puncta prorsus idivisibilia & inextensa; puncta materialia*), but among these points were acting **continuous** forces, which were initially, at the lowest distances, repulsive, then turned to be attractive, and so on (Fig. 2). Assuming dimensionless points and continuous forces, Bošković did not develop only a sound physical theory, but resolved, too, the paradox of atomism, which stemmed

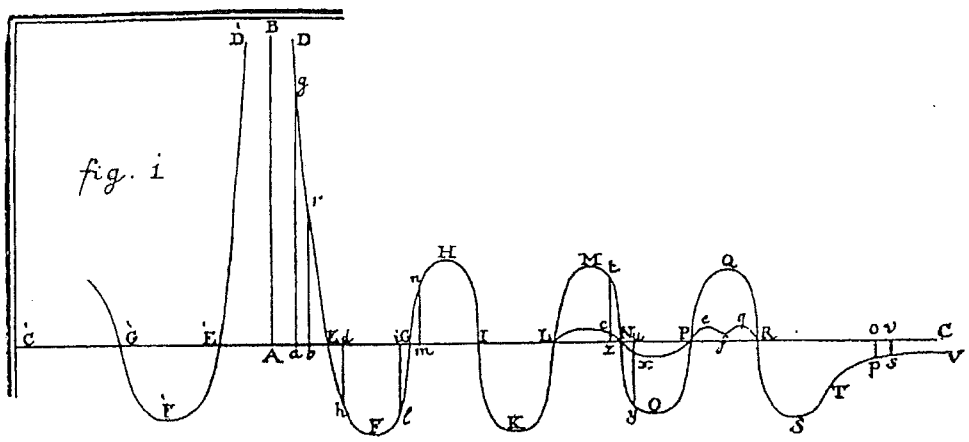

Fig. 2 – *Bošković's curve, qualitative plot of force between the atoms vs interatomic distance. The repulsive force at close distances was proposed to explain inponderability of matter, and attractive force at larger distances is responsible for cohesion. [Taken from Ref. 37]*

Slika 2 – *Boškovićeva krivulja, kvalitativni graf sila među atomima u ovisnosti od međuatomske udaljenosti. Odbojna sila na malim udaljenostima objašnjava neproničnost materije, a privlačna sila na većim udaljenostima odgovorna je za koheziju. [Preuzeto iz ref. 37]*

from the Kantian second antinomy of pure reason: how the smallest particles could be both indivisible and infinitely divisible. From the viewpoint of Bošković's theory, *punctum materiale* is a physical equivalent to "absolute punctuality", and forces between atoms are the consequence of "absolute continuity", to use Hegel's terms, of time and space.

As the Epicurean view led to stoichiometric concept of atom, Bošković's theory may be regarded as a philosophical basis of contemporary force-field methods, of which molecular mechanics[38] is the most popular. With respect to the basic Leucippus's concept of atoms and the void, it suffices to say that concept of molecular volumes, namely the van der Waals volume (i. e. volume of atoms) and free volume (void around the atoms in molecule), gave rise to a number of theoretical models,[39–41] which have been used for study of solvation and kinetics, and even in conformational analysis.[40,41]

However, the value of Plato's theory has not been recognized until the rise of quantum mechanics. *Werner Heisenberg* stated that original Democritus's theory led to a misleading concept of atom, for atoms had been regarded as if they were macroscopic bodies.[42] But "immateriality" of atoms, quite in lines with Plato's philosophy, is the very foundation of quantum theory: atoms are viewed as an impression of Schrödinger equation upon matter, just as were Platonic bodies. Moreover, assuming ultimate elements of matter to be triangles, entirely "immaterial" entities (because they lack volume), *Plato* anticipated that constituting elements of atoms (particles) are not particles, but "immaterial" wave functions.* View of chemical reactions as a rearrangement of geometrical bodies, which is the very base of stereochemistry, is also along the lines of Platonian atomism.

Conclusion

The atomic hypothesis, proposed 2500 years ago by Greek philosophers *Leucippus* and *Democritus*, should not be viewed merely as an anticipation of modern chemical and physical theories. Atomism gave not only solutions to the philosophic problems of the day, but opened the questions which would have the fruitful influence on the science and philosophy till our times (Fig. 3). To speak about all the influences it should be necessary to write a book on history of, both, chemistry and philosophy; but I would like to stress only four leading ideas which originated from the atomic theory:

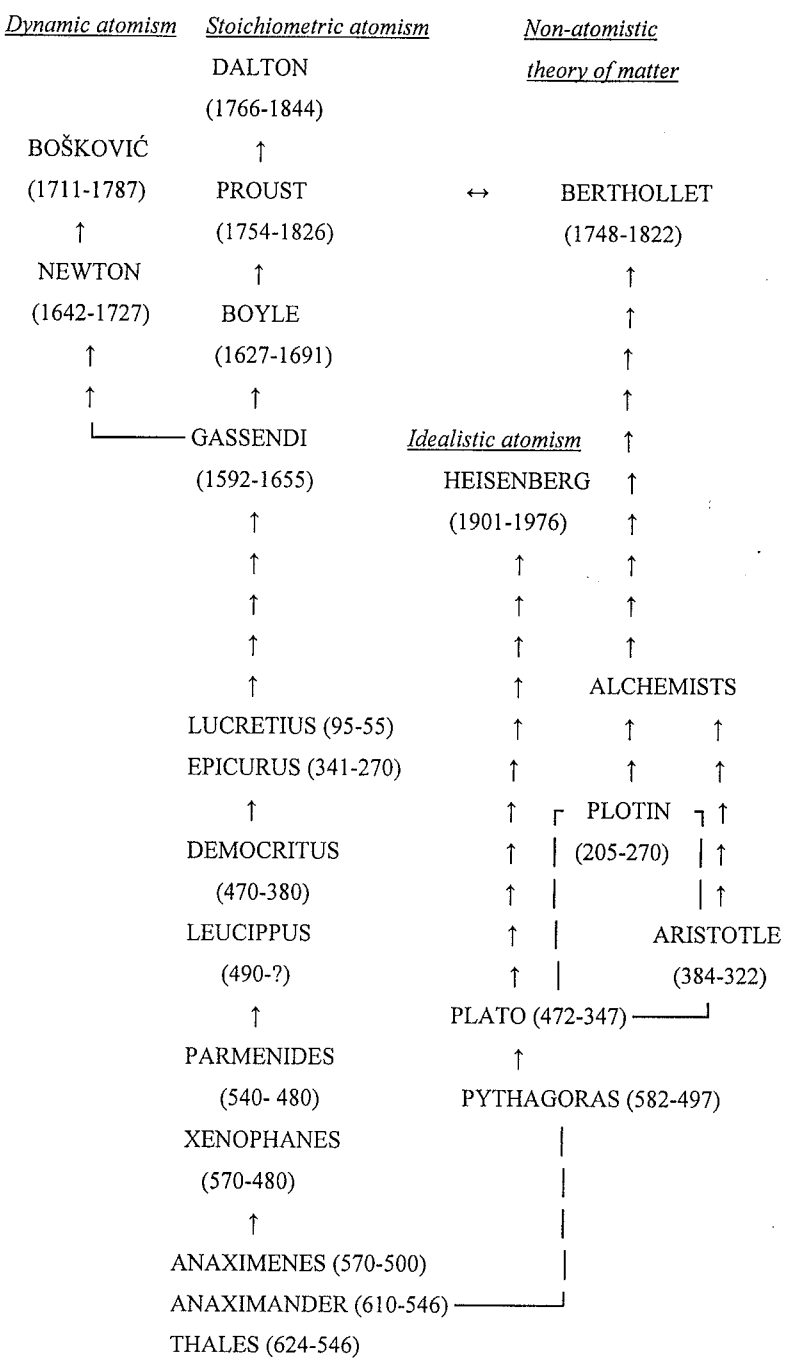

Fig. 3 – *Scheme of historical development of theory of matter. There are four general tendencies: (1) matter is regarded as constituted of particles differing in mass (stoichiometric atomism), (2) properties of matter are derived from the attractive and repulsive interactions among the constituting particles (dynamic atomism), (3) ultimate particles of matter are viewed as consequences of an "immaterial" reality (idealistic atomism), and (4) matter is regarded as continuous plenum, assuming that all chemical changes are essentially qualitative. The last chemical theory which did not necessarily include atomic hypothesis, was due to French chemist Claude Louis Berthollet, who was trying to show that Proust's law of constant proportions was not universally valid.*

Slika 3 – *Prikaz povijesti teorije materije kroz četiri osnovna smjera razvoja: (1) smatra se da materiju čine čestice koje se razlikuju po masi (stehiometrijski atomizam), (2) svojstva materije izvode se iz privlačnih i odbojnih međudjelovanja čestica od kojih je sastavljena (dinamički atomizam), (3) smatra se da postojanje najsitnijih čestica materije proizlazi iz neke "nematerijalne" zbiljnosti (idealistički atomizam) i (4) materija se smatra neprekinutom puninom, što vodi do postavke da su sve kemijske promjene u biti kvalitativne. Posljednju teoriju u kemiji koja nije nužno zahtijevala prihvaćanje atomističke hipoteze dugujemo francuskom kemičaru Claudeu Louisu Bertholletu, koji je pokušao pokazati da Proustov zakon stalnih omjera ne vrijedi apsolutno.*

*The Schrödinger equation, $H\Psi=E\Psi$, separates primary qualities of matter, Ψ, from its secondary, experimentally obtainable ("sensual") qualities, E. But he secondary qualities can be derived (i. e. calculated) from the primary qualities, in spite of their "immaterial" (ideal) nature. This is the very core of Greek atomism.

1. Problem of the nature of movement and, consequently, the nature of space and time. Atomic theory did also open the question of the real existence of empty space (void, vacuum).[43,44]

2. Problem of divisibility *ad infinitum,* which is the cornerstone of atomic hypothesis, led to the revelation of deceptions of the (pure) reason, which were crucial for development of Kant's revolutionary philosophy.

3. Assumption that all qualities can be derived from the movement of atoms, leads to the mechanistic view of Nature (all natural phenomena are reducible to elementary processes), which is the foundation of modern science.

4. Democrit's distinction between primary and secondary qualities furnishes the basis of all modern scientific theories. We take nowadays for granted that elementary processes and components does not resemble macroscopic (i.e. subjective) appearance of things.

At the end, I would like to conclude my paper with a statement, that close resemblance of speculations of the Greeks to modern scientific theories does not show, of course, their super-human power of prophecy, they rather shows that the ways of solving scientific problems are determined by the basic philosophic concepts, which are consciously or unconsciously conceded.

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SAŽETAK

Atomizam u grčkoj filozofiji

N. Raos

Pojam atoma, "nedjeljive čestice", izvire iz spekulativnog odgovora grčkih filozofa *Leukipa* i *Demokrita* na paradoksalnu koncepciju bitka koju je postavio *Parmenid*. Atomsku je teoriju kasnije razradio *Epikur*, koji je dao novo rješenje problema gibanja i nedjeljivosti atoma. *Aristotel* je kritizirao atomsku hipotezu, niječući zbiljsko postojanje praznog prostora (vakuuma) i dokazujući da je materija beskonačno djeljiva. Platon je pak smatrao atome pravilnim geometrijskim tijelima sastavljenima od nematerijalnih dijelova – trokuta.

Uz pregled razvoja atomske teorije među Grcima, članak se bavi i utjecajima grčke filozofije na razvoj dinamičkog atomizma u 18. stoljeću, a posebice teorijom hrvatskog znanstvenika *Josipa Ruđera Boškovića*. Odrazi grčkog atomizma mogu se pronaći i u modernom mehanističkom objašnjavanju kemijskih i fizičkih pojava (*Demokrit*), u stehiometrijskom shvaćanju atoma (*Epikur*), kvantno-mehaničkim i stereokemijskim modelima (*Platon*) te modelima temeljenima na molekularnim obujmovima (*Leukup*). Atomska teorija koju je postavio *J. R. Bošković* našla je svoj odraz u modelima teorijske kemije koji se temelje na konceptu polja sila.

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