EARTH'S CRYOSPHERE
SCIENTIFIC JOURNAL

Earth`s Cryosphere, 2020, vol. XXIV, No. 6, pp. 3–8 **http://earthcryosphere.ru/**

CONCEPTUAL PRINCIPLES OF CRYOLOGY

DOI: 10.21782/EC2541-9994-2020-6(3-8)

CONCEPTS OF COLD IN CHANGING PERCEPTIONS OF NATURE: DEVELOPMENTS FROM SPECULATIVE KNOWLEDGE TO CRYOSOPHY

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The growing differentiation between the spheres of knowledge that largely hinders the creation of a holistic scientific worldview based on interdisciplinary synthesis has become one of the fundamental problems of modern natural sciences. This situation is expressly illustrated by the history of geocryology. Originally this discipline studied natural objects and subzero-temperature phenomena from the narrow perspectives of geographical and geological sciences alone, however by the beginning of the 21st century the diversity of objects and methods of cryological research has extended way beyond the realm of natural sciences. This urged the need to pool the knowledge gained and apply the multidisciplinary approach. Cryosophy which was primarily intended for this problem solution has thus been recognized as a new field of philosophy of science. The main objective of cryosophy as science consists in raising awareness of the importance of cold matter in the evolving matter – energy interplay in the universe in the context of origin and maintenance of life on the Earth. Development of the concept of cryosophy threw light on its general situation: geocryology as highly specialized discipline of natural sciences has existed not more than one century, while the history of philosophical views on the role of cold which is rooted in antique natural philosophy spans the period of at least 2500 years. Ancient Greek philosophers formulated a number of fundamental questions about the properties of cold matter and its role in nature. Deepening of philosophical views on cold became possible only at the postnonclassical stage of science which is marked by the attempts to create scientific worldview on the basis of systemacity, interdisciplinarity and the principles of universal evolutionism.

Philosophy of science, speculative knowledge, natural philosophy, cryosophy, cold, interdisciplinarity, postnonclassical science

INTRODUCTION

Overcoming the ever increasing differentiation between disparate subject domains and scientific disciplines that study various natural objects, phenomena and processes is a problem of paramount importance in modern natural science. Emergence of new fields of knowledge prompted by new discoveries is inevitable in the near future. However, the study of natural phenomena from new research perspectives and multiplication of the fields of knowledge gained from them often compromise wholeness of the concepts of its subject matter.

Geocryology as a science emerged more than a hundred years ago due to the mankind's growing interest in the high latitudes and the need to address threats and challenges in conquering the Arctic Ocean. The ensuing flow of information abounded with characteristics of ambient environment temperature, coastal structure, ice cover dynamics, spatiotemporal variations in frozen ground, etc. The Arctic warming phenomena cycle has raised hopes of regular maritime activity in the high north. Attempts to drill through the permafrost and Middendorf's report on soil temperature measurements in Shergin shaft dug to a depth of 116 m in 1829 stirred the imagination of the inlanders.

In its concepts and methods, the young science stemmed from geology and geography. However, the scope of subjects and methods of geocryology has expanded enormously over its short history. Widely recognized by the beginning of the 21st century, methods of geocryology have been actively involved in all kinds of permafrost investigations considering the cryosphere (the Earth's cold sphere) as part of the geosystem encompassing the atmosphere, hydrosphere and lithosphere. The lines of research into cryogenic phenomena increasingly comprise the physical and chemical properties of the cryosphere's objects, the role of cold in the evolution of biota (cryobiological issues) and humans (anthropogenesis). In this context, by using the terms of different scientific disciplines for the study of disparate cryological processes and phenomena and their interpretation, the geocryological community could be likened to the builders of the Tower of Babel who became unable to continue their common work in accord, once they began to speak different languages.

Thus, the most important methodological problem of many other postnonclassical natural sciences is systematicity and interdisciplinarity [*Stepin, 2011*].

The late 20th–early 21st century exponential growth of knowledge entailed the need to harness coherently integrated diversity of scientific representations of the world as the basis for a holistic view of the world. Fully understanding the seriousness of this problem, the authors and their like- minded peers have paid key attention to development of the underlying methodologies and paradigm of cryology (both terrestrial and extraterrestrial), in order to finally create a basis for cryosophy as a new line in philosophy [*Melnikov, Gennadinik, 2011*]. The mission of cryosophy consists primarily in systematic study of the role of cold in the inception and evolution of matter-energy interactions in the Universe, with a particular focus on origin and maintenance of life. Cryosophy as science seeks to offer new future prospects, and different kind of guidelines and beacons (like myths) for fundamental research into the evolution of the cryosphere in all its diversity, using both classical (for simple physical and chemical systems) and synergetic (for complex systems and living matter) approaches, as well as information logistics methods that generate knowledge about knowledge [*Melnikov, Gennadinik, 2012*].

THE CONCEPT OF COLD IN NATURAL PHILOSOPHY

Studies of cold, as well as many other natural phenomena are deeply rooted in ancient Greek natural philosophy, which flourished between the 7th and 4th centuries BC. Note that natural philosophy in that era was a single undifferentiated discipline, not yet split into philosophy and natural sciences, leaving aside the more detailed later division [*Rozhansky, 1979*]. Natural philosophy studied the world as a whole; the Greek thinkers tried to pick essential principles (elements) of the nature in their versatility and interactions and made their conclusions from direct observations of the natural phenomena, through the lens of speculative knowledge[1]. In the early history of ancient Greek philosophy, cold seemed interesting primarily as representative of constituents in the system of opposites (or contraries) in nature. Thus, for Parmenides, warm and cold were elements like fire and earth [*Aristotle, 1981*]. Anaximander of Miletus viewed the world as a scene of interacting essential opposites extracted from the infinite (*apeiron*) which was the source of all things. Kessidi [*1982*] noted that, according to Anaximander, all perceptible things (the Earth and terrestrial beings) were formed through interactions of the opposites, and the existing world order is but an immanent cosmic justice (dikë) ensuring eventual return of all things to the *apeiron*: each of the opposites, winning over the other, commits an injustice towards it.

Thus, the assertive cold tends to whelm the warm, the dry whelms the wet and vice versa, while the apeiron maintains the overall balance and prevents the opposites from winning one over another [*Kessidi, 1982*]. Heraclitus developed Anaximander's theory and was the first to formulate the idea of *Logos* as a universal rhythm, measure, and order. As fundamentals of dialectics, Heraclitus understood transformation as replacement of one element by another: what is cold becomes warm and what is warm becomes cold; what is wet becomes dry and what is dry becomes wet [*Kessidi, 1982*]. The unity of opposites making up a single whole is the central idea of Heraclitus' philosophy, with the emphasis laid on the fact that each opposites is inseparable from its other. Heraclitus viewed this as a dynamic system, in which all things and phenomena could change and transform into their opposites [*Kessidi, 1982*].

One of the key questions at that evolution stage of science was whether cold is a physical substance or a universal property of any matter. Thus, Anaximenes, a follower of the Milesian school of thought, considered cold and heat to be transient states of matter, rather than definite substances. As he affirmed, anything, which undergoes contraction and condensation of matter, is cold, while anything that suffers rarefaction and distention is hot [*Fragments..., 1989*]. Anaximenes treated air as an element of any matter, which can acquire various physical states associated with its condensation or rarefaction and thus provides the diversity of things in the surrounding world [*Rozhanskiy, 1979*].

Plutarch's *On the Principles of Cold* was among earliest special treatises on the cold world [*Plutarch, 2000*]. The philosopher inquires whether there exists an active principle or substance of cold (as fire is of heat) or if coldness is rather a negation of warmth, as darkness is of light and rest of motion [*Rozhanskiy, 1979*]. Plutarch insists that cold is not mere negation or privation of heat, but is rather a positive substance or force that can make change to matter like heat. Furthermore, in his speculations on cold, he marked its capability to produce affects and alterations in bodies that it enters no less than those caused by heat. Many objects can be frozen solid, or become condensed or made viscous, by cold. This is one of the particular effects produced through the agency of cold, which could not be justified by negation of

[1] Speculative knowledge (lat. speculation = observe, contemplate) a type of knowledge largely underlying metaphysics, without recourse to experience, that seeks to explore the limits of science and culture. Not only does speculative knowledge rise above the empirical experience, it also surpasses theoretical knowledge, the subject matter of philosophical thinking [*New Encyclopedia of Philosophy, 2001*].

warmth alone. Besides, rest in frozen things is not mere inaction but rather stability, which is due to the consolidating and compressing capacity of cold [*Rozhansky, 1979*]. Plutarch came to a conclusion that the primordially cold is the earth, and criticized earlier assumptions of the Stoics ascribing it to the air, and Empedocles and Strato (Aristotle's disciple) to water [*Rozhansky, 1979*].

The great merit of Greek philosophers was that they were the first to seek explanations for the framework role of cold in the physics of the Earth and the cosmos. Anaxagoras tried to understand how an ordered world of cosmos emerged out of the formless primordial matter [*Rozhansky, 1979*]. His concept was largely based on the idea that the dense, the moist, the dark and the cold, all the heaviest things collected in the centre and consolidated, and thus gave birth to the Earth [*Rozhansky, 1979*].

Plato and Democritus who laid the foundations of the theory of atomism tried to explain the effect of hot and cold by the action of tiny invisible particles: atoms.

Plato distinguished two varieties of water: "liquid" water and "fusible" water; the former refers to all fluids and the latter to solids that can melt and flow under the action of fire. The former is liquid because it is made up by water molecules of different sizes, whose heterogeneity precludes their holding tightly together, and they easily move relative to each other – both by themselves and under the action of external forces. Whereas the latter type which is made up by large homogeneous molecules allowing for their tight packing is more stable and heavier than the former. However, due to destructive effects of the invading fire it loses its uniformity [*Rozhansky, 1979*]. The contribution of Aristotle's physiophilosophical views into the theory of cold was the greatest. He considered cold and heat as elements producing the properties of matter by making it dense or solid [*Aristotle, 1981*]. In his views, the opposites of cold/hot and dry/ wet, combined in different ways, formed the four elements of fire, air, water, and earth [*Aristotle, 1981*]. According to Aristotle, the combination of these properties gave rise to four elements: fire, air, water and earth. Cold acted as an integral part of the last two elements (cold + humidity = water; cold + dryness = earth) [*Aristotle, 1981*].

Developing the ideas of Anaximenes and Heraclitus, Aristotle postulated the existence of a single matter common for the opposites of hot and cold (i.e. there will be some 'matter', other than either, common to both) [*Aristotle, 1981*]. He supplements this theory by the following illustration: if air results out of water, the same matter comes out to be another [body], not by means of attaching something, but [simply] because what was potentiality becomes actuality. And the reverse [conversion] of water from air will occur in the same way: once from a small quantity to a large one, and once from a large one to a small one. Similarly, when a large amount of air transforms into a small mass and from a small [mass] comes out to be a large one, the matter that exists as potentiality becomes both [*Aristotle, 1981*].

He was among the first thinkers to focus on the issues of cold and its role in atmospheric phenomena (like hoar, dew, snow, and hail), and his account of hoar-frost and dew which form on the ground surface is given below: Some of the vapor that is formed by day does not rise high because the ratio of the fire that is raising it to the water that is being raised is small. When this cools and descends at night it is called dew and hoar-frost. When the vapor is frozen before it has condensed to water again it is hoar-frost; and this appears in winter and is commoner in cold places. It is dew when the vapor has condensed into water and the [sun] heat is not so great as to dry up the moisture that has been raised nor the cold sufficient (owing to the warmth of the climate or season) for the vapor itself to freeze [*Aristotle, 1981*]. For dew is more commonly found when the season or the place is warm, whereas the opposite, as has been said, is the case with hoar-frost. For obviously vapor is warmer than water, having still the fire that raised it: consequently more cold is needed to freeze it [*Aristotle, 1981*]. Aristotle then continued: From the latter there fall three bodies condensed by cold, namely rain, snow, hail. Two of these correspond to the phenomena on the lower level and are due to the same causes, differing from them only in degree and quantity. For rain is due to the cooling of a great amount of vapor, for the region from which and the time during which the vapor is collected are considerable. But of dew there is little: for the vapor collects for it in a single day and from a small area, as its quick formation and scanty quantity show. The relation of hoar-frost and snow is the same: when cloud freezes there is snow, when vapor freezes there is hoar-frost [*Aristotle, 1981*]. Aristotle argued that hail forms when the warmth still present in lower layers of the atmosphere (external heat) embraces the descending cloud, while cold is pushed deeper inside it, thereby making the water contained therein freeze.

Summing up the contribution of Greek philosophers into the knowledge of cold, it is pertinent to note that the problems they formulated were actually a breakthrough for the science of that time and remain essential nowadays. The issues they covered were:

- cold as one of opposites in the system of natural elements (Parmenides, Heraclitus, Anaximander, Anaximenes, Aristotle, etc.);
- material carriers of cold (Plutrach, Empedoclus, etc.);
- cold as a universal property of matter (Anaximenes, Aristotle, etc.);
- effect of cold on state change in natural objects (Aristotle, Plato, Democritus, etc.);

• cold as framework in the structure of the Earth (including its atmosphere) and the Cosmos (Anaxogoras, Anaximenes, Aristotle, etc.) [*Melnikov, Fedorov, 2020*].

Of course, the ancient knowledge was insufficient to find realistic solutions and many speculative hypotheses on the nature and features of cold did not hold up.

However, the very formulation of problems had a great scientific value and became precursor to the basic objectives of cryosophy thousands of years before it originated. After the period of classical antiquity, the development of the theory of cold and its properties remained suspended for centuries, because the syncretic ancient natural philosophy dispersed into several sciences in the Hellenistic times, the natural sciences decayed in the Middle ages, etc.

The interest to cold as an agent in various natural phenomena and processes rekindled during the Renaissance. Thus, for Bernardino Telesio, the 15th century Italian scientist, natural sentience was the very activity promoted by the forces of heat and cold in their constant attempts to give shape and structure to the world. Telesio is famous for his critique of the Aristotelian worldview, in particular his ideas about the role of cold [*Popov, Styazhkin, 1983*]. The 18th century was another milestone, with Isaac Newton's law of cooling and Scala Graduum Caloris. Calorum Descriptiones & Signa (Scale of the Degrees of Heat. Description and Signs of Heat) that came out in 1701, where he suggested a scale of 12 degrees between the melting point of ice and body temperature. In 1750, Michael Lomonosov published his work *On the Causes of Hot and Cold* where he proved that the temperature, or the heating degree of bodies, was a measure of motion of small physical particles [*Lomonosov, 1951*]; hence, the predicted by him state when the particles stop moving corresponded to the greatest degree of cold. In those and other studies of that time, the apprehension of cold as affecting the structure and properties of matter advanced actually in terms of the basic problems put forward by the Greek philosophers [*Butorina et al., 2013; Grigorovich, 2015*]. Alternatively, positivistic thinking that set in the methodology of science in the 19th century implicitly ruled out the possibility of turning back to ancient philosophical approaches to the nature of cold. While the positivists rightfully criticized the physiophilosophical attitudes, which often imposed speculative ideas of natural objects and processes, they were wrong to extrapolate that criticism onto philosophy as a whole, and to negate its basic principles and ideas as off-cast "metaphysics" [*Stepin, 2006*]. At the same time, the principle of empiricism jointly with criticism pushed the metaphysics into the marginal background, isolated it from the empirical thinking and left in an unstable and equivocal position [*Stolyarova, 2018*].

That was the setting in which the observations of Haurace de Saussure, Alexander Humboldt, Alexander Middendoff, Karl Baer, Peter Kropotkin, and others created prerequisites for glaciology, a new science of ice and glaciers that appeared in the latest 18th century, as well as for geocryology, a science of permafrost that formed in the 20th century. In their early history, both glaciology and geocryology were mostly descriptive sciences based on field observations concerning the extent and physical properties of permafrost, ice, and snow.

CRYOSOPHY, THE SYSTEMATIZED APPREHENSION OF THE COLD WORLD

The threshold of the 20th–21st centuries was marked by enormous extension of the scope of objects and lines of research into the cold world. At this, many studies of cryogenic phenomena have been closely related to the classical subjects of geology and geography, as well as to various problems of physics, chemistry, biology, medical sciences, pedology, ecology, climatology, cosmology, etc., which led to changes in the axiological comprehension of cold. Thus, in the 1920s permafrost was treated as ill in terms of practice, which can by exemplified by P.I. Koloskov's preface to the book by M.I. Sumgin describing the becoming of the science of permafrost [*Sumgin, 1927*]. Nowadays, rather than being a danger, the sphere of ice and cold is increasingly viewed as cryogenic resources and new potentialities for the mankind, and its role in human development has not been completely understood [*Melnikov, 2012*].

The meaning of the term "cold" has also been clarified and is interpreted as "the condition of a specific environment in which its loss of heat energy leads to a decrease in the temperature of this environment prior to the formation in it of water ice under normal circumstances or a similar gas hydrate under high pressure" [*Sheinkman, Melnikov, 2019*]. A few years ago the term *cryodiversity* was coined to help understanding the diversity of objects and phenomena associated with cold and phase change of H_2O, as well as forms and properties of ice as a focus of theoretical research [*Melnikov et al., 2013*]. The properties of the cryosphere can be best illustrated by a model of a multi-function system of ice with six main components (hierarchies) where: the two sides of the "space" axis represent the hierarchy of objects and media in which ice is the major control; the "energy" axis illustrates the phase states of ice and its functions; the "time" axis presents cryogenic systems in terms of information, resources, and cybernetics (i.e. the cryosphere changes the characteristic times and rates of processes and stores records of the other terrestrial spheres, which has an intimate relation with synergetic processes and with the life origin and evolution). The concept of cryodiversity covers multiple biotic and abiotic (bioinert) complex systems, such as cryophilic bacteria that live in permafrost, atmospheric precipitation, gas hydrates, etc.

Application of the methods available in cryology and cryosophy to the study of cryodiversity requires taking into account all the elements of the cold-controlled system, failing which leads to erroneous estimates of its state. We may add that the evolution of life and its environment inevitably experiences effects of changes in the Earth's cryosphere. The Earth's cryosphere is a second-order system in the supersystem of the Universe-scale cryosphere; in its turn, it has its subsystems, such as different <0 °C atmospheric layers, cryogenic-nival system, cryohydrogenic system, cryolithosphere, etc. Cryosophy can therefore be interpreted as advanced methodology for the study of the cryosphere aiming to continually contribute to its big picture by using the knowledge gained from scientific and geoengineering research, and complemented with literature and artistic clues.

According to the views of V.S. Stepin [*2006*], complex self-evolving systems are arranged hierarchically and can generate new hierarchic levels. Note that the philosophical system of Aristotle likewise presents the world as a hierarchic system with dynamically interacting elements of different levels. In this respect, there is an overlap between the objectives of Greek physiophilosophy and the modern postnonclassical science. The ancient thinkers had a syncretic view of the world and put forward basic problems of scientific knowledge, to which, however, they could not find the solutions, given limited methodological and instrumental facilities of that time. The idea of such holistic approach remained for a long time a remote ideal[2] until real opportunities appeared for the postnonclassical science which acquired new features as prerequisite for the creation of an integrative worldview [*Stepin, 2006*]. However, a fundamental scientific breakthrough became possible in the late 20th century by integration of the three existential levels – nonliving, living, and social – with a focus on cryogenic phenomena.

Yet injustice would be done to the thinkers of the past, if we didn't give greater detail of how views of the ancient Greek philosophers have been developed in cryosophy. The role of cold in the system of opposites is often considered in the modern science in terms of dialectics. For instance, the phase transition of ice from solid to liquid and back illustrates the principle of transition from quantity into quality.

Aristotle, Plutarch and other philosophers tried to understand the role of cold in the formation of the elements at the base of natural objects, while cryosophy studies transformations and interactions of hydrogen and oxygen, the primary and secondary elements[3], whose aggregation and hydrogen bonding laid the basis of both inert and organic matter. The very evolution of the Universe, since the matter emerged from the elementary particles of protons, neutrons, and electrons at the big bang, has been associated with hydrogen that formed first (together with helium) upon cooling [*Melnikov, Gennadinik, 2012*]. The systemic value of cold in the physical structure of the Earth and the extraterrestrial space, which interested Anaxagoras and other thinkers of Ancient Greece, is the principal subject of cryosophical research on cryogenic systems in the terrestrial and extraterrestrial evolution. Thus, complex behavior of crystal habits of ice and its phase transitions away from equilibrium states, in themselves, are sufficient to organize ordered synergetic behavior, to form stable macroscopic objects. This is illustrated not only by snowflakes, which have been studied since the first scientific reference to snow crystals made by Johann Kepler and are interpreted as the most widespread complex cryogenic object, but also by spatially ordered structures formed by water drops in atmospheric clouds [*Shavlov et al., 2011*].

CONCLUSIONS

Philosophical apprehension of cold dates back to the ages of Ancient Greece. Aristotle, Plutarch, Heraclitus, Plato, Democritus, Anaximenes, Anaxagorus, and Anaximander were the first to formulate the basic problems concerning the cold matter, its properties and role in the world. It was yet impossible to find the solutions in terms of the metaphysical world view of that time. Paradoxical as it may seem, it took more than two thousand years for science to approach the understanding of the problems put forward by the physiophilosophy of the classical antiquity. It became feasible due to a) new axiological paradigm of cold with its environment-forming and resource values; b) interdisciplinary integration of natural, humanitarian, mathematical, and engineering sciences that study various objects and processes associated with cold; c) viewing the cryosphere as a complex system (terrestrial cryosphere as a second-order system in the Universe-scale supersystem). However, unlike Greek physiophilosophy which claimed to be a universal syncretic science, cryosophy can be generally perceived (much like philosophy of science) as a unity of philosophical reflection on science and "scientific reflection on philosophy" (its recourse to philosophy) [*Kasavin, Porus, 2016*]. Cryosophy is a kind of integrator, which attracts different fields of knowledge related to the cold world and builds a framework for its ontology. The integrating and framework

[2] In this connection, it is pertinent to mention Leonardo da Vinci's structural projects brought to life centuries later.

[3] In current scientific understanding, elements were released in the wake of the Big bang in successive stages (surges), as follows: I – hydrogen and helium; II – from lithium to iron; III (after new cosmic explosions) – more massive (heavier than iron).

role of cryosophy is consistent with the global trends in philosophy of science evolving from a "real science" to its epistemological comprehension through generalizing models and evolution principles [*Lebedev, Kos'kov, 2014*]. S.A. Lebedev and S.N. Kos'kov called this tendency a self-comprehension of science which began at its nonclassical stage and gained ever increasing significance in the postnonclassical history of its epistemology and philosophy [*Lebedev, Kos'kov, 2014*]. In the case of cryosophy, it has been the first attempt to formulate a system of cognitive views of terrestrial and extraterrestrial cryogenic objects, phenomena, and processes integrated into the emerging holistic scientific worldview.

The study was conducted under the government-commissioned task (AAAA-A19-119071990006-3) and supported by the Russian Foundation for Basic Research (project No. 18-55-11005 AF_t).

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Received June 1, 2020
Revised version received July 25, 2020
Accepted August 4, 2020