Cryosophy, or Principles of Life in the Cold

<table>
<thead>
<tr>
<th>Journal:</th>
<th>The British Journal for the Philosophy of Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manuscript ID:</td>
<td>Draft</td>
</tr>
<tr>
<td>Manuscript Type:</td>
<td>Article</td>
</tr>
<tr>
<td>Keywords:</td>
<td>cryosophy, geocryology, phase transfers</td>
</tr>
</tbody>
</table>
Nowadays, the growth of our knowledge of the cold and phase transition of water stands out even against the background of avalanche-like increase of scientific information in general. Such phenomena are diverse and unique, they concern both living and non-living matter, but at the same time are easily observed, important for human activity, and can reveal certain resources yet unused, as well as factors of sustainable development.

The observed and growing diversity – “cryodiversity” - needs description, analysis and subsequent systematization. Essential at the moment is a philosophical study of the object, purpose and methods of cryology in view of its interaction and cooperation with other sciences, which constitutes a new philosophical approach in ontology - cryosophy [13].

**Origins of cryosophy**

Philosophy, like art, is the innate need of a person cognizing the world. Why is it so important to determine the concept of “cryosophy” in natural science and philosophy? There are several reasons for this. *The first one* is connected with steady human expansion over new areas (Fig.1).

Conventional knowledge and ideas concerning the cold - the basis of cryosophy – started forming in the ancient times, and were developing in proportion to the advance of people towards the north latitudes and their need for survival in the severe climate. These processes were accompanied by changes in worldview and mentality, gradually transforming into beliefs and principles; new knowledge conquered fears and superstitions, and new adaptive qualities enabled people to fight for better life conditions and develop new territories.

*The second* reason is associated with the growth of knowledge, and is stipulated by the significance of low-temperature processes and processes connected with phase transitions of water and other substances for the contemporary scientific ideas of cryosphere. An example of this is permafrost science, or geocryology, a study of cryogenic and sometimes rather unexpected
transformations of the lithosphere when soils and deposits are cooled below freezing temperatures.

It becomes quite obvious that some fundamental processes in the microworld, in soil studies and biology, meteorology, geophysics and cosmology are connected with the cooling and phase transitions of water to ice. For instance, it is highly possible, that crystallization of water, capable of polymerization – reaction of a great number of molecules together - influences the development of complex organic molecules at the stage of life-formation. Freezing can be a cause of salt concentration, which is a condition for a simple protein forming. According to Arrhenius – Goldansky hypothesis, life was conceived in the cold clouds at cryogenic temperatures as a result of the impact polymerization and other processes [6]. Ribosomes tend to be more functional at low temperatures, which can be the evidence of the fact that life was conceived under cold conditions [5]. Or, if life has an extraterrestrial origin and was brought to the Earth from other planets, the cold obviously played the role of a preserver. Search for extraterrestrial life is focused on the cold regions of the satellites of Jupiter, Mars and other planets; moreover, one of the most intriguing issues nowadays is the detection of life in subglacial lakes of Antarctica.

The structure of water can be represented as a mixture of hydrated – ice like structures. This is of great significance for understanding the vital activity of organisms. It has been proven that the structured form of water in brain synapses ensures the transfer of pulses from neuron to neuron. An ice-like film around DNA increases the effective diameter of DNA macromolecule in water solution by 40%, in comparison with the waterless state of DNA macromolecule, and that is important for data extraction. Even minor heating (to 50-60°C) leads to protein denaturation and stops the functioning of living systems. Meanwhile, cooling down to complete freezing and even to absolute zero does not lead to denaturation and does not disrupt the configuration of biomolecules, so the vital function after thawing may be restored. Similar behavior is common for enzymes providing for metabolism in organisms [4].
The third reason is connected with the increasing economic value of the cryosphere. The resource base of energy industry is being moved northwards, as far as up to the shelf of the Arctic Ocean (Fig. 2). Expansion of loess – the belt of deposits with extremely unfavorable properties that stretch across the entire northern hemisphere, failures of buildings, roads, and bridges due to the insufficient frost resistance are all caused by the freezing-thawing cycles (Fig. 2). Almost a half of structures beyond the Polar circle experience threatening deformations and failures. Roads and highways both in Russia and in Canada are not in the best state, and the reason for that is not only the quality of construction and building, but also omnipresent frost heaving. Safety of oil and gas pipelines is determined by permafrost processes to a considerable degree.

The cold becomes the foundation of technologies, and this is the fourth reason. The increasing demand for practical use of low temperatures determined rapid development of refrigeratory and cryogenic technologies in the 20th century. Development of nuclear energy, aviation, electronics, food and chemical industries, medicine, exploration and transport of natural gas would be impossible without the application of the cold. Extraction, storage, transport and practical use of many industrial gases is carried out within the wide range of low temperatures (0.3 – 165°K). In the 20th century their production was constantly increasing along with growing needs of chemical and metallurgic industries, aviation, astronautics, defense industry, energy, biology, medicine, electronics etc.

Development of space technology and nanotechnologies stimulated the creation of cryovacuum systems and apparatuses. The largest in Europe cryovacuum camera with the volume of 10000 m³ was built in the Soviet Union by Prof. V. Belyakov, and was used for testing “Buran” spacecraft. One of the most significant problems is preservation of helium for the future generations. The obtained portion of helium does not exceed 10% of its content in the natural gas, and the major portion vents to the atmosphere and diffuses to outer space. The first in the world passenger aircraft on liquid hydrogen and liquid natural gas (Tu-155) was designed in
Russia and flew to Nice, Hannover and Berlin in 1990-1991. The cold was used to freeze the ground during the construction of Moscow subway in the mid-1930s. In the fifties, scientists created unique cryogenic equipment to remove carbon dioxide from the air of subway stations, and later similar systems were developed for air recycling in submarines and spacecrafts.

Another innovation was cryoexplosive technology of processing of old tires.

Cryosurgery and cryotherapy (cryosauna) are also developing very fast. Cryogenic storage of sperm, embryos, bone marrow, blood, which started in the 1960s, is widely used now. The gene pools of global and national plant reserves are kept in cryogenic depositories produced in leading countries of the world. A wide range of unique diagnostic methods in medicine are ensured by the use of superconductivity and magnetic nuclear resonance. All of the above makes it possible to say, that the cold has been actively utilized in both medicine and biology during the past two decades, and will undoubtedly be used even more actively in the future.

Finally, the fifth, and, probably, the main reason consists in the fact that physical phenomena in the cryosphere not only become part and parcel of science and technology, but they also concern the most important issues for mankind. In particular, the state of the universe before the Big Bang and immediately after it, the cold dark matter, distant future of the universe, origins of life and its presence on other planets, origins of intelligence and even possibility for life prolongation, - these issues are, one way or another, deeply and almost mysteriously connected with the cold.

**Concept of the cold**

In order to determine the “concept of the cold” and its significance for philosophy and natural sciences, we should first consider some of the basic philosophical categories. Matter is a philosophical category for designation of substance possessing the status of fundamental principle (objective reality) in the materialist philosophical tradition, in contrast to the
consciousness (mind). “The cold” can be considered as a philosophical category, which defines
the category of the “state” of matter and its unique hypostasis.

Category of “state” was developed in natural sciences, although its philosophical status was not
sufficiently explored. Fales claimed that “the essence remains, and states change” [1].

Democritus considered the transient states as the expression of the eternity of motion [1], and
Lucretias pointed out that “everything passes from one state to another” [17]. “State” was an
important concept in the philosophical system of Plato, who believed that the passage of space
from the state of “ancient order” to the state of the “best order” is directed by God, and that the
state of “ancient order” yields the forms of things [16]. The concept of “state” has been fully
introduced to philosophy by Aristotle in his book “The categories”, who defined it as “… such
forms of qualities that easily yield to fluctuations and rapidly change, for example, heat and
cold…” [10]. State, according to Aristotle, is a particular case of quality: “any body experiencing
these states is something real and a certain essence” [2]. Thus, “the cold” as essence emerges at
the time of Aristotle, although it also is the form of connection between the qualities of matter.

Later the concept of “state” was used by G. Leibnitz [9] in the form of ideas concerning
contiguity and interrelations of states. Kant’s point of view is somewhat close to Aristotle's:

“change is the way of existence, which follows another way of existence of the same object” [8].

And, of course, the concept of “state” is comprehensively revealed by G. Hegel, whose
qualitative differences in the objects determine their stability. According to Hegel, qualitative
changes are expressed by the concept of the leap, which is similar, in essence, to a phase
transition of one qualitative state to another, for example, to the transformation of water into ice.

It is of interest, that Aristotle stated that the category of energy is primary in relation even to
matter, human soul being a form of energy. Medieval reformation of scientific approach, though,
emptied out the concept of energy, reducing it down to the concept of “horse power”. At the
same time, Wilhelm Ostwald believed that energy is the only universal substance, which, to a
certain degree, complies with modern concepts of physics.
In the newest history, the science of cold was conceived within the study of heat in the 18th century in the works of I. Newton “Of the scale of the various degrees of heat and cold” (1701), M.V. Lomonosov “Reflections upon the causes of heat and cold” (1744), and L. Euler “Of the nature of heat” (1752).

Cryogenic processes, formations and conditions and their spatial-temporal appearances

The key object of cryology is ice and, in particular, its phase transitions. It was not by accident that the temperature of phase transition of ice to water under atmospheric pressure was chosen as a reference point for scales of Celsius and Reaumur. Ice is sometimes considered as a simple byproduct of water transformations. Everybody knows about three aggregate states of water, but nobody refers to three aggregate states of ice. Here we are obviously dealing with our subjective perception of the world: water is instinctively (and biologically) more appealing to us than ice. However, variability of states of water and ice are incomparable. Ice has 17 crystalline modifications; there is an enormous variety of ice forms in the earth's crust and the atmosphere.

The definition of planetary ice can be as follows: ice is the chemical compound of the basic elements of lithosphere and lower layers of atmosphere of planets, a solid body, which is converted into the liquid or gaseous state with the change of conditions, which has, as a rule, a crystalline structure with the micro- or macroinclusions of liquids, gases and solid particles. Thus, the most common forms of ice include aqueous, carbon dioxide, methane ice and the ice of gas hydrates.

Ice unites the contrasting properties: crystal - amorphous body, elasticity - plasticity, semiconductor – dielectric, lighter than water – hard as a steel knife [11]. Complexity of its inner structure and characteristics of its phase transitions far from being on the side of equilibrium are already sufficient for the formation of a well-ordered synergetic behavior and stable microscopic objects. Found on the energetic scale between water and vapor is one of such objects - “drop
clusters”, steady dissipative structures in the form of well-ordered miniature balls of condensate, having identical diameter and formed in the gradient region above the locally heated liquid phase [19]. Similar phenomena can turn out to be a missing link between the inert and living matter. Presence of cryosphere changes the essence, characteristic time and speed of geological and biological processes. Cryosphere is connected with cycles; moreover, this cyclic recurrence is noticeably diverse. In the “cold season” (for the northern hemisphere it is autumn - winter - spring) circadian (diurnal) cycles are important for cryogenic systems. Water-ice phase transitions stabilizing temperature conditions for the living occur during the period of twenty-four hours. A change in the meteorological conditions with the periodicity of daytime also increases the number of cryogenic cycles. Quite a few processes are caused by these circadian cycles – frost cracking, physical (cryogenic) weathering and others. The annual cyclic recurrence of cryosphere is a reason for snow and ice to be in steady state for a longer period, creating cryogenic conditions. In the polar regions the circadian cycles are naturally absent (polar day and night last for half a year) and living creatures are adapted to this (for example, reindeer have very special biological clock). The cryosphere is also influenced by longer cycles: eleven-year and 270-year solar cycles, as well as astronomical cycles of other periods.

A more complex cyclic recurrence is observed in glaciers. The evaporated molecules of ice are crystallized on the temperature atmospheric filter in the clouds and fall down as snow. If snow does not melt during the warm season, a glacier - a viscoplastic body of ice – is accumulated. Under the action of gravitational forces, the glacier gradually flows to the region of ablation, where it gets mechanically destroyed, melts and evaporates. Thus, any glacier determines its own natural characteristic period of time, depending on climate (temperature and humidity) and geography (relief and geological structure). The periodicity of the cycles can be diverse, from several years in the mountains and the subarctic, to tens of thousands and more years in Greenland and Antarctica. Study of cycle interaction in such systems is an interesting research task.
One of the most urgent scientific problems nowadays is the problem of global warming. The structural elements of the cryosphere are among the objects that are first to experience the effects of warming, but to a variable degree.

It is the presence of the atmosphere with its temperature screen aggregating the molecules of water to ice particles, which prevents water from leaving the Earth. This is the key factor making it possible for life to appear on our planet. All changes in the cryosphere of the Earth influence the formation and evolution of the environment. Ice, the basic component of the cryosphere and the predecessor of water – formed at the first moment of the existence of the universe, with the formation of hydrogen and, a little later, oxygen. Their aggregation and hydrogenous bonds are the basis of both living and nonliving matter. The fact that the mean annual temperature of the Earth was close to the point of ice-water phase transition for such a long time is a very fortunate, as far as life is concerned, but quite natural phenomenon (Fig. 3).

Ice, just like water, has unique thermo-inertia properties, which in combination with their prevalence on the earth's surface allow the cryosphere to serve as a thermostat. Heat capacity of water (4,183 kJ/(kg•K)) is 5 times higher than the average heat capacity of soil, and its volumetric heat capacity is 3,3 thousand times higher than the heat capacity of air. High heat capacities of water and ice (2,060 kJ/(kg•K)) make them the main solar energy storage batteries on the planet. The point of phase transition itself has additional, and anomalous, thermostability. Latent heat of ice (332 kJ/kg) is 5 times larger than that of gold (66.2) and 28 times larger than that of mercury (12). Thermal stability determines conditions favorable for the formation and evolution of living organisms. Ice serves as a life protector, stabilizing parameters of the environment.

We still do not know exactly what brought to life multicellular organisms approximately 900 - 1000 million years ago [18]. The obvious and increasing need of oxygen for multicellular organisms is traditionally explained by its gradual accumulation in the atmosphere due to photosynthesis, but their initial development could be connected with the increase of its
concentration in cold water due to massive ice formation on the planet, as well as with special characteristics of the circulation of water at this time (Fig. 4 and 5).

It is of interest that it was in this cold epoch of the Vendian that the first gigantic organisms appeared - gigantism, as is well known, is typical of the Polar Regions, and is connected, among other factors, with the specific heat exchange.

The epochs of temperature drop and the evolution of living organisms prove to be interrelated during the entire Phanerozoic Eon. The most considerable epochs of extinction can be linked to the temperature drop before the Jurassic, and then at the end of the Cretaceous. The appearance of Homo sapiens occurred during the most significant ice age, and the role of temperature drop in the origin and development of man is still unclear and needs to be studied (Fig. 6). Why, for example, did art first appear during the coldest time of Pleistocene?

Cryogenesis triggers some geological processes that are as diverse. Formation of tillites and moraines, glacial eustatic movements are to name just a few, as well as less known phenomena like formation of iron-manganese concretion (IMC) belts in the world ocean, probably caused by the disturbance of circulation of flows due to the sea ice formation and the distribution of gases in water. Resources of IMC in the world ocean are distributed with the mysterious nonuniformity: 85% of manganese and more than 95% of rare metals are concentrated in the equatorial part of the Pacific Ocean. Such uneven distribution (Fig. 7) could be evidence of the fact that a reducing environment was formed under ice near the Polar Regions, and later the material was transported towards the equator, where ice oxidizing situation remained in the regions free from ice, and the formation of concretions could occur. It is possible that the accumulation of ferrous quartzites on the Earth is caused not by the activity of iron bacteria, but by the fluctuations of oxygen in water due to temperature changes. Reduction of entropy during the formation of complex organic molecules and biopolymers in the process of life formation could also be connected with a temperature decrease and ice influence, but very little is known about the early stages of the Earth's development.
It has been revealed that life survives on ice. Our studies [14] show that microorganisms can exist in ancient permafrost as single cells, i.e. life is capable of long-term conservation. Microorganisms can be located inside the ice crystals, deprived of any exchange with the environment (Fig. 8).

One of practical tasks of scientists is to obtain medicines that could increase the quality of life, something that permafrost provides microorganisms with in the extreme environment. Ice is also a screen protecting from fatal radioactive emissions; it is a thermostat with the minimum temperature gradients, and a protector against the chemical and biological mutagens. A cryogenic system slows the time down inside the Earth's layers and accelerates it on the boundaries, creating strong gradients of development. For instance, paleobacteria can be preserved for the anomalously long periods of time by ice screens.

Another widespread phenomenon is worth mentioning, an example of which is supercooling water. In spite of being well-known, nature of metastable states is still not fully understood. For example, it is still unknown, for how long water can remain supercooled - months, years, or maybe an unlimited amount of time. Metastable states are much more common in nature than is generally believed. They include not only glass formation, but also recently discovered metastable gas hydrates [23].

Hydrolysis, as is well-known, is one of the most important chemical reactions both for living and nonliving matter. Weathering, in particular, is to a considerable degree caused by hydrolysis. Chemical reactions are possible even in the solid phase, and the existence of nonfrozen films on the surface of ice determines the possibility of reactions, which are similar to hydrolysis, but in the solid state. They are poorly studied and can be referred to as “cryolysis”.

This incomplete list of “cryodiversity” manifestations just outlines the importance and perspectives of further investigations into the cryosphere.
Cryogenesis as the basis of cryodiversity

There are four basic characteristics of ice: anomalous thermodynamic and electromagnetic properties, intermediate intensity of hydrogenous bond, metastable states (supercooled water, amorphous ice, gas hydrates), and the wide distribution of cryogenic systems and conditions.

Anomalous thermodynamic and electromagnetic properties of ice.

Anomalously high heat capacity, specific heat of fusion and dielectric constant are among primary ice properties. They form global climate, determine existence of ice screens of different scales - from self-preservation of gas hydrates to permafrost on continents. The unique thermo-inertia properties of ice and water, in combination with their prevalence on the earth's surface, allow the cryosphere to serve as a thermostat. Consequently, the characteristic rates of geological and biological processes decrease, which leads to the formation of untypical objects with non-characteristic temporal and spatial features.

Intermediate intensity of hydrogenous bond.

Ice crystals may be considered to be a standard of hydrogenous bonds. The hydrogenous bonds are weaker than covalent ones approximately by an order, and that explains their high mobility. The hydrogenous bonds play the most important role in biochemistry. Water determines the speeds of biochemical reactions and many life-long characteristics of living matter.

Wide distribution of cryogenic systems.

Due to the Earth's geochemistry and geological history, ice and water occur on the surface of the planet in three aggregate states [15]. Other planets have their own cryogenic systems. Mars, which is close to the Earth, has polar caps and permafrost that consist of water and carbon dioxide. Outer planets were formed of lighter matter and contain methane and hydrogen. Interestingly, light gases there are under lower temperatures and they are also subject to phase transfers. Therefore, cryogenic systems are common in the whole of the Solar system.
Cryosophy and its role

Cryosophy is a scientific view on place and role of the cold in the origin and evolution of living and non-living matter, including the evolution of man. It studies essential characteristics and fundamental principles of the cryosphere. The key to the knowledge management is to develop the ontology of the cryosphere - the detailed formalization of the field of knowledge using the system of interconnected concepts [12]. The main task of a researcher is to reveal this actually existing system of relationships. Cryology increasingly more frequently operates with some terms that are quite unusual for classical applied science: diversity, stability, complexity etc. All this gives to cryology the features of a post-non-classical science. Methodology of the new science comes as cryosophy; and remaining within the framework of the old and quite narrow methodology, geocryology will not be able to satisfy the imperative of time.

Literature
6. Goldanskiy V.I., Trachtenberg L.I., Flerov V.N. tunnel phenomena before chemical physics, Moscow, 1986


Fig 1. Life beyond the polar circle (RIA of Novosti).
Fig. 2 Computer agents (colored dots) simulating prehistoric hunter-gatherer groups are superimposed over a map of Late Pleistocene western Eurasia. Gray shows Pleistocene land area with lowered sea levels, black lines show modern coastlines, white areas show ice sheets. The blue dots represent groups of "modern" humans, red dots represent groups of Neanderthals, and yellow dots represent groups with biological mixtures of modern and Neanderthal genes [26].
Fig. 3. The thermal history of the Earth [24]

![Diagram of the thermal history of the Earth]

Fig. 4. Proterozoic ice formations and related events: the enrichment of atmosphere by oxygen and the appearance of new organisms [22].

![Diagram showing Proterozoic events and oxygen levels]

Fig. 5. The cold epochs of Proterozoic, change in the chemical composition of oceans and the evolution of living organisms [22].

![Diagram showing Proterozoic epochs and changes in ocean chemistry]
Fig. 6. Change in the environment and the evolution of man [20].
Fig. 7. Resources (IMC) in the world ocean [3].

Fig. 8. Single cell before the frozen species [14].