ICE AND FLAME

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"In the same place," Swift continues to joke, "I saw another scientist who burned ice into gunpowder. He showed me a study he had written on the malleability of a flame, which he is going to publish." Now everyone can see that it was necessary to joke more carefully. The ice is burnt into gunpowder today. This was done by people with whom jokes are bad. We mean the creators of the hydrogen bomb. The nuclei of deuterium atoms contained in the water merged into helium nuclei, forming a thermonuclear reaction in the form of a grandiose explosion.

This fragment from V. Orlov's "Treatise on inspiration that gives birth to great inventions" (Moscow, 1964) once again confirms that the most incredible and daring projects, even taken from Gulliver's humorous description of the Academy of Projectors by Gulliver, can eventually become reality. Moreover, it is possible that they are the way out of the most acute and inexorably impending crisis - the fuel and energy crisis. After all, now from the water they really learned to extract not only fuel (oxygen + hydrogen), on which some rockets and cars work, but, as Orlov correctly noted, also energy.

So far, this thermonuclear energy is tamed with difficulty, being effectively released only in the process of an uncontrolled explosion. But science is inexorably approaching the implementation of a controlled thermonuclear reaction of fusion (fusion) of deuterium nuclei, and, moreover, from different sides, increasingly compressing the ring of the environment. Magnetic traps for plasma are being improved (recently one of them was launched in France), laser nuclear installations, even hopes are pinned on the mysterious cold nuclear fusion (see "Engineer" No. 6, 2005).

So over time, this rebellious energy of the future will also be curbed. "Future", because the energy of fusion, in contrast to the energy of nuclear decay or chemical combustion, is one of the cleanest and most environmentally friendly. But most importantly, the reserves of this energy are practically inexhaustible and accessible to all: thermonuclear fuel (deuterium) can be obtained directly from water. Moreover, as shown by an interesting calculation from the book of I. Petryanov [1], one liter of plain water can produce the same amount of energy as 120 kg of high-quality coal. So just imagine what incredible energy reserves the World Ocean conceals!

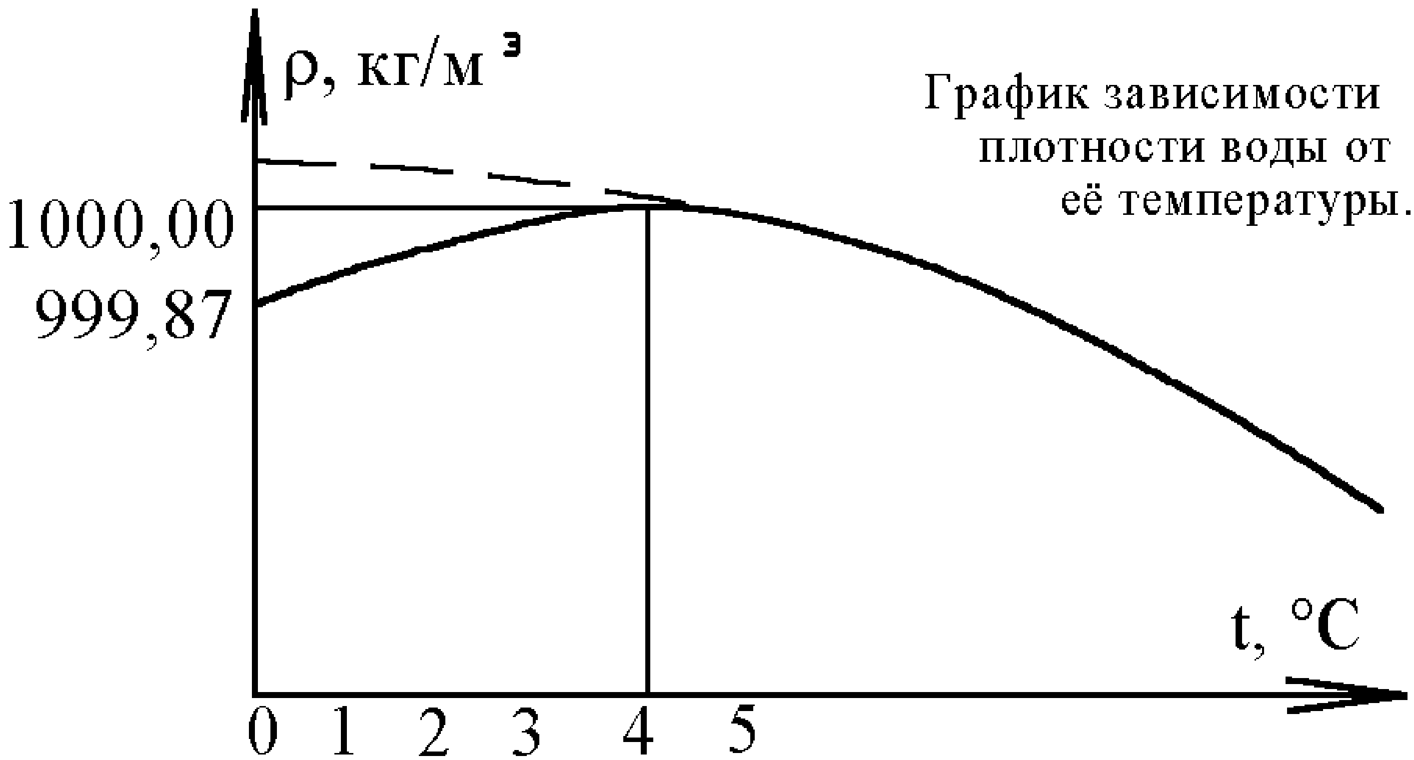
Equally important is the fact that water is available everywhere. This means that there will be no need for exploration of oil, coal and gas deposits, there will be no reasons for fuel wars, the unleashing of which marked the beginning of the new millennium. What a dispute can be when the energy is here: come and draw it at least with a bucket. However, not everything is so simple, because deuterium has yet to be extracted from the water. This heavy isotope of hydrogen (designated "D") is found in water in the form of a compound called D_2O called heavy water (thanks to deuterium, it is 1.1 times heavier than plain water H_2O). So, the next problem after the problem of controlled thermonuclear fusion is to solve the problem of the extraction of heavy water.

In principle, this problem has already been solved, and heavy water can now be obtained in relatively large quantities. However, the process of its isolation is complicated and expensive, and heavy water is usually obtained not from water, but from other substances containing deuterium. Indeed, in a ton of plain water, there are only about 150 g of heavy water. D_2O can be separated from H_2O using the difference in their physical and chemical properties. So, if H_2O boils at 100° C, then D_2O - only at 101.4° C. The difference is almost imperceptible and therefore hundreds of successive distillations are needed before it is possible to isolate sufficiently pure heavy water from the water. This is exactly how - by multi-stage distillation (although usually not water itself is distilled, but hydrogen), electrolysis and other multiple operations and it is possible to obtain deuterium. Accordingly, the process is very costly and time-consuming. Therefore, better and more economical ways of extracting D_2O from water would be very useful .

In this regard, it seems interesting to assume that in nature, over millions of years, there can be a gradual natural release and accumulation of heavy water in some unknown reservoirs. After all, year after year, nature does nothing more than repeated re-distillation. Water evaporates from the surface of reservoirs, and then condenses in the form of rain, which is why the concentration of heavy water in reservoirs should gradually increase. This idea is suggested by the fact that the content of deuterium in rain, river and sea water differs markedly [2 , p. 99]. Yet the existence of lakes with heavy water is in great doubt; millions of years of accumulation in them D_2O would go down the drain because of the rare accidental flooding of them with plain water. Different waters mix too easily in reservoirs to be worth looking for liquid D_2O in them. The geographer M. Adzhiev's hypothesis is much more probable, according to which there may be deposits of frozen heavy water - "heavy ice" [3] . Then ice would become an effective supplier of thermonuclear fuel and energy, like Swift's, and not just water. Indeed, the melting points of D_2O and H_2O are much further apart from each other than their boiling points. While plain water freezes at 0° C, heavy water only freezes at +4° C. Therefore, with repeated recrystallization, the separation of D_2O should be more efficient than distillation.

Considering that in many places on the Earth ice and snow either melt or freeze again, the process of natural accumulation of heavy water can indeed take place in them. It is no coincidence that in many glaciers the content of deuterium is increased in comparison with the norm, although not by much. And since heavy ice is not able to mix with plain water, then the layers of heavy ice that freeze layer by layer could indeed be preserved somewhere in the form of powerful glacial layers.

However, it is likely that the release of heavy water occurs not only somewhere in secluded places, but also in our sight. Many may have pondered the amazing ability of water to expand when frozen. But its other property is much more unusual: unlike all other liquids, water reaches its highest density not at the point of crystallization (0° C), but at a temperature of +4° C. That is, when heated in the range from zero to 4° C, water does not expand, like any liquid, but contracts (see graph). And only after passing over 4° C, when heated, the water begins to behave like all normal liquids, that is, it expands.



It is believed that the abnormal compression of water is due to the fact that, even in a liquid state, it partly retains the molecular structure of ice, which finally decays only upon strong heating. And since ice is lighter than water, its structure makes water less dense. As the temperature rises, the ice-like structure of water becomes less and less pronounced, the water turns into a truly liquid state, and its density increases, reaching a maximum at 4° C, after which thermal expansion prevails over the compression process.

But until now, no one has explained why water in a liquid state retains an ice-like structure. And the answer is perhaps simple: when heated above zero, only simple water H_2O melts , while a small amount of heavy water D_2O remains in a crystalline state: its melting point is thus 4° C. It is at this temperature that heavy water will finally melt. And, therefore, starting only from this temperature, the water will expand. Since the D_2O molecules in water are too scattered, they probably form hybrid crystals containing D_2O and H_2O in different proportions . Therefore, all these crystals have different melting points (depending on the isotope ratio), intermediate between 0 and 4° C. In this interval, the crystals gradually melt: first they are fusible, then more and more refractory, which is why the density of water in this interval is grows gradually, and not abruptly. Pure water, which does not contain isotopes, should obviously show the normal course of the dependence of density on temperature, that is, it always expands when heated (see the dotted line in the graph).

So, even in the refrigerator, when freezing or thawing water, the process of isolation, fractionation of heavy water from its solution in ordinary water should proceed. If we could somehow precipitate crystals of heavy water, drain them out of solution, or just wait until they merge into one large one, then we would get a compound highly enriched in D_2O. And the separation of pure D_2O would become much cheaper.

But are we too carried away? Does heavy water actually precipitate near the crystallization point? Is this consistent with scientific evidence? Is there evidence of this, besides the fact that the melting point of D_2O and the temperature of the highest density of H_2O coincide? It seems that yes. On the one hand, no one doubts that when ice melts and water freezes, isotopes are fractionated, heavy water is released from its solution. On the other hand, according to many scientists, and in particular G. Stewart, cold water not only has an ice-like structure, but contains real microcrystals of ice, numbering thousands of molecules and forming, as it were, "snow spots, ice floes floating in a pool of water" [2]... X-ray studies of water confirm this point of view. The presence of such ice floes in water cannot be explained, unless we assume that these are crystals of heavy water.

Let us also give a quantitative confirmation of the hypothesis. The density of water at 0° C is 999.87 kg/m^3, and at 4° C it is and at 4° C it is exactly 1000 kg/m^3 (see graph). That is, a ton of water at 0° C has a volume of 0.13 liters more than at 4° C. The same ton of water is known to contain 0.14 liters of heavy water D_2O, which, when frozen, increases in volume (like ice) by one tenth, more precisely by 0.013 liters, which, although less, is still comparable to the observed change in volume by 0.13 liters. In addition, we must take into account that crystals, as we found out, can be hybrid, i.e. include, in addition to D_2O molecules, also H_2O molecules . Then the total volume of crystals will be several times greater than 0.013 liters.

So, nothing prevents heavy water from separating out of solution in the form of ice. In addition, there is some other evidence that speaks in favor of the formation of heavy water crystals. So, everyone has heard about the medicinal properties of melt water. Many, including the aforementioned Adzhiev, explain this effect by the fact that freshly melted water retains the crystalline structure of ice for some time, and by the fact that when it melts in water, the content of heavy water, harmful to the body, decreases (it remains frozen in ice) ... Indeed, it is known that the life-giving water of mountain streams originating in melting glaciers is depleted in heavy water (this is a direct consequence of the higher refractoriness of heavy water - it thaws last). Such deuterium-depleted mountain water is even called "living water" (while enriched with deuterium - "dead") [4] . Some authors consider it to be the source of mountain longevity.

Let us cite as evidence such a rare phenomenon as bottom or intra-water ice, colorfully described in Jack London's story "On the Forty Mile". The phenomenon consists in the fact that ice begins to form not, as usual, on the surface, where cooling is more intense, and the temperature is close to zero, but for inexplicable reasons it appears near the bottom. At the bottom layer of water, not only is heat extraction low, but also the temperature is far from the freezing point: it is thus equal to +4° C (water with the highest density sinks to the bottom). Moreover, bottom ice forms not only in winter, when there is still no ice on the surface, but sometimes even in summer. Not surprisingly, the story of the Jack Londonian hero about this phenomenon was not believed. And yet the phenomenon really exists, Science recognizes it, but it cannot yet reliably explain it. Well, in fact, how can water freeze at 4° C? Yes, even if it froze, the ice would immediately float to the surface!

But everything is easily explained if, like Adzhiev, we assume that the bottom ice is formed by heavy water. Heavy water freezes and is released most intensively just at 4° C. Moreover, the resulting heavy ice, in contrast to simple ice, has a density almost the same or even slightly higher than that of water. Therefore, it will not float, unless more "light" molecules of simple water "freeze" on it. The only strange thing is that D_2O molecules are capable of forming large conglomerates in the form of bottom ice. After all, as we found out, if D_2O is released from water, it is only in the form of tiny crystals with a diameter of several tens of atoms, and therefore not distinguishable either with the eye or with a microscope. But this is only true for small volumes of water.

In the river, the conditions are somewhat different. There, a huge mass of water flows over each section of the bottom per unit of time, and crystals of heavy ice are frozen out of its entire volume. Having a density somewhat higher than that of water, they settle for a long time to the bottom and freeze into relatively large crystalline conglomerates. Apparently, this is why the bottom, or intra-water ice weakly resembles ordinary ice: according to the description, it looks more like snow - it is a white loose mass of frozen crystals. It is not for nothing that bottom ice is compared in appearance to corals. The validity of the hypothesis could be verified by an elementary measurement of the density of the bottom ice. If it turns out to be noticeably larger than that of a simple one, then this ice, no doubt, is formed precisely by heavy water. It is also possible to directly determine the deuterium content in the bottom ice.

So, if Adzhiev's hypothesis is correct, then heavy water, released in nature in the form of crystals, could be obtained in huge quantities and, moreover, almost free of charge. It would only be necessary to explore where the bottom ice most often occurs, or forms deposits. Perhaps it is even worth trying to push and intensify this natural process by creating special stations on the rivers for the production and extraction of bottom ice. In fact, this will be another way to use the free energy of flowing water, the sun and temperature fluctuations, but given the enormous "energy value" of heavy water, it is much more efficient than in hydroelectric power plants, wind power generators and solar power plants.

However, even at the present time, until an effective controlled thermonuclear reaction has been implemented, the possibility of extracting heavy water from ice may turn out to be useful and cost-effective. After all, cheap heavy water would be useful right now - medical institutions, research institutes, and nuclear power also need it. And it is in Russia, which has the largest ice reserves among all countries, the maximum number of glaciers, icy streams and rivers, that one should seriously think about extracting heavy water from it. Who knows, maybe in the future it will turn out that ice and snow are the second most important natural resources of Russia (the first, as V. Orlov's wonderful books show, has always been and will remain Russian ingenuity and ingenuity). Then the time will come to forge the ice into a flame.

Sergey Semikov

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