Why Does Ice Float on the Surface of Water?

Muzaffar Iqbal

The regular mail pouch that went with the caravan from Khwārazm to Bukhāra on a certain spring day had a letter from Abū Rayḥān al-Bīrūnī for Ibn Sīnā. The letter continued their discussion from where it was left in the previous letter, but this time al-Bīrūnī asked two additional questions: (i) If things expand on heating and contract on cooling, then why does a sealed flask full of water break upon freezing? (ii) Why does ice float on the surface of water although it is closer to earthly nature in its accumulation of cold and in its concrete solidity?

"The answer to your first question is already present in the question itself," responded Ibn Sīnā in a letter carried by the returning caravan. "When the body contracts upon cooling, it takes less space; this creates a vacuum inside the flask and that breaks it. As for your second question: water preserves its airy qualities while freezing, and these prevent it from sinking."

"This completes our answers to all your questions," Ibn Sīnā added in a postscript. "Faqīh al-Maʿṣūmī has already shown me the final and neat copy of my response, so it will reach you in good time and if you have further questions, do not hesitate to refer them back to me, and from Allāh comes all our abilities and from Him is succor."

When the letter arrived in Khwārazm, al-Bīrūnī eagerly read it, but the answers did not satisfy him. "I have broken as many flasks as would hold the waters of [the river] Jayḥūn," he said half-

Muzaffar Iqbal is Founder-President of the Center for Islam and Science (*www.cis-ca.org*). Email: Muzaffar@cis-ca.org.

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jokingly in his next letter, "and they all *break outwardly*, like a body when it cannot hold what is in it. So, if what you have said were correct, then they should have *collapsed inwardly*, not break outwardly. As for the air entering water when it is cooled, when does that happen?"

"Your objection to what I have said about the breaking of the flask and saying that it should have broken inwardly because of vacuum are both invalid," responded Ibn Sīnā. "The cause of breaking is coming from within, because when water gathers coolness and solidifies inside the flask, it leaves a little space between itself and the wall of the flask: that space longs for something to occupy it, because it is impossible for a space to remain empty. That natural longing breaks the flask, but it is hard to differentiate through observation whether it is breaking from within or without. In any case, the breaking from without would be severe because the outside surface is greater than the inside surface, and also because extreme cold shrinks bodies; this creates a crack, just as cracks appear on the surface of ground during cold weather.

"With regard to the floating of the ice on the surface of water: although ice is colder than water, it floats because it contains airy particles. Some ice however may sink, because it may have fewer airy particles and hence would be denser. The proof that ice has air particles is that it can be crushed inward, whereas bodies which do not have such airy pockets cannot be pressed inward. "And as for your question about when air enters the ice, the answer is: it happens during the process of its solidification, because it is the cold air which causes the solidification. And Allah knows best."

We do not know what al-Bīrūnī thought of these responses, as further correspondence has not been preserved, but we now know that when water freezes, it expands, and hence ice is less dense than water. Al-Bīrūnī was, therefore, right in saying that a sealed flask full of water breaks outwardly because water in its frozen state needs more space than in its liquid form.

We now know that water is one of the few known substances whose solid state is less dense than its liquid state. In addition, we also know that water is made up of two atoms of hydrogen and one atom of oxygen. Both hydrogen nuclei bind to the central oxygen atom through a covalent bond formed by a pair of electrons. Since only two of the six outer-shell electrons of oxygen are used for this purpose, the remaining four electrons (organized into two non-bonding pairs) arrange themselves as far away from each other as possible in order to minimize repulsion between clouds of negatively charged electrons. However, because the two non-bonding pairs are closer to the oxygen atom, they repel the two covalent bonding pairs, effectively pushing the two hydrogen atoms closer together. The result is a distorted tetrahedral arrangement in which the H—O—H angle is 104.5°, instead of a tetrahedral geometrical structure in which the bond angle of H—O—H would have been 109.5°.

Al-Bīrūni and Ibn Sīnā were not able to see the electronic clouds as we can now, and although they knew, just as we do now, that opposite charges or states attract and similar charges repel each other, they did not have tools to determine the exact angles of the H—O—H bond in a water molecule. They also had no way to ascertain that the electronic (negative) charge is concentrated at the oxygen end of the molecule, owing partly to the nonbonding electrons and partly to oxygen's higher nuclear charge which exerts stronger attractions on the electrons. This charge displacement constitutes an electric dipole, so that the partially-positive hydrogen atom on one water molecule is electrostatically attracted to the partially-negative oxygen on the neighboring molecule. This process, somewhat misleadingly called hydrogen bonding, is an amazing feature of the water molecule which is primarily responsible for many physical properties that distinguish it from other small molecules of comparable mass. Most of these "anomalous" properties of water—which are by no means mysterious, unpredictable, or abnormal—depend on the extremely weak hydrogen bonding, so weak that a hydrogen bond does not survive for more than a tiny fraction of a second. But still, it is this hydrogen bonding that is responsible for a large expansion (about 9%) in the volume of water between –4°C and 0°C.

A second and perhaps more important anomalous property of water is its high boiling point. According to what we now know about the properties of compounds the size of water, it should boil at around minus 90°C; that means it would normally exist in the world as a gas rather than a liquid, but its hydrogen bonding, though very weak, once again produces this phenomenal change in the physical properties of water.

All of this is well-known and even elementary information that can be found in any chemistry textbook, which would also tell us about many other amazing properties of water such as its unique surface tension, that allows an insect to walk across the surface of a pond and a child to be amused by floating a small paper clip or steel staple on the surface of water in a cup. One can rationally understand that this happens because the molecules at the surface of the pond or the cup do not experience attraction to the neighboring molecules in all directions (only sideways and downward, since there are none at the top), and hence the resulting forces do not average out to zero—as they do in the bulk of the liquid—and, consequently, there is surface tension which is particularly prominent in water because of its relatively strong hydrogen bonding.

Modern science and its tools have allowed us to understand these and many other properties of the water molecule, but it has no way of answering *why* ice floats on water; it can only tell us *how*. There is nothing wrong with this inherent limitation of science, for all disciplines of knowledge work within certain boundaries, and this allows us to organize various branches of knowledge in a hierarchy of interconnected disciplines. Problems arise, however, when there is nothing to connect various disciplines or if one discipline is given undeserving place in the hierarchy. Scientism does exactly this; it claims for science an undeserving authority and takes its methods as the only means of understanding the nature of reality. Consequently, it limits reality itself to only what can be studied by tools and methods used by science.

This Comtian Positivism, which ultimately goes back to the Greeks, reduces water to a substance consisting of two atoms of hydrogen and one atom of oxygen attached to each other at a certain angle and having certain physical and chemical properties. There is no more to it. Thus reduced to the limits of sense perception, the water molecule studied so minutely by modern science is shorn off its ontological and the cosmological dimensions, leaving behind a residual structure floating in a Godless universe of molecules deprived of any teleology. This tyranny of matter having gained supremacy over all else and granted an autonomous status then renders all investigation into the types of relationships between existing things superfluous.

This reign of matter is a relatively new development. Until the emergence of modern science, scientific questions were addressed as part of metaphysical inquiry, and though metaphysicians of old are still held in some esteem in modern Western thought, paths available to the practitioners of modern science for connecting what they study to that which lies beyond their experiments, observations, tools, and instruments are now virtually nonexistent. As a logical outcome of this severance of modern science from the hierarchy of knowledge, the highest level anyone can achieve by investigating the properties of water by means of modern science alone is that of mere wonder (*taḥayyur*); a necessary, but only the first step toward a true gnosis of the nature of things as they really are.

Yet, if water were merely a substance consisting of three atoms, which, in turn, are merely a combination of various subatomic particles, then there is no possibility of ever knowing anything about it beyond its sheer physicality; there are no paths available for asking *why*; we can only ask *how* questions. The positive answers we will receive to such questions will come with a thinly veiled exclusivity insisting that any further inquiry beyond atoms and their configurations is irrational, perhaps even unintelligible and in any case mere speculation.

Yet, it is precisely at the limits of science that one stands in front of the gates of great mysteries and it is precisely beyond wonder where begins one's journey to the kind of knowledge that can show the nature of things as they really are. For it is only after knowing the not-so-mysterious reason for the floating of ice on the surface of water that one can begin to ask: had ice not floated on water, what would have been the fate of millions of life cycles beneath the frozen crust of oceans? Had water boiled at minus 90°C, how would life be possible?

This is not yet another variation of the centuries-old argument from design advanced by Plato, Aristotle, Cicero, Augustine of Hippo, Thomas Aquinas, and numerous Muslim thinkers of the premodern era and hollowed out by their successors who would find Darwinian explanations far more convincing. Nor is this an attempt to reinvent the old teleological argument in a manner reminiscent of the anthropic principle; the human race now stands too close to the apocalyptic closure of time to use yet again the manifest delicate balance, which has created conditions necessary for life, as an argument only to be refuted by those who see nothing behind this balance but blind chance. That none of the finite range of possible structures for the water molecule exists except the one which creates conditions for the existence of life is all too obvious for any need of a speculative philosophy. The improbability of achieving such a structure by mere chance is also obvious. In addition, there are thousands of other examples spread in the far reaches of the cosmos as well as within ourselves which have been documented without convincing the skeptics that there is a design in existing things and that design implies a designer. For every argument, a counter-argument can always be made. Even a mundane event, such as that of getting any particular hand of thirteen cards in a game of bridge, can be, and has been, used to counter the design argument, for such a probability is approximately one in 600 billion. It would be absurd, so goes the argument, to examine the hand carefully, calculate the odds, and then assert that it must not have been randomly dealt. It is, therefore, mere chance. The water molecule just happened to arranged itself in the particular configuration in which it exists, a configuration which makes life possible. It is mere chance, an accidental "hit".

If complexity does not imply design, or if design is merely by chance, and if life has just emerged by chance and continues to exist in this wonderful variety out of a raw biological propensity for survival—then neither the ice floating over water nor any number of other observable phenomena constitute convincing arguments for a Designer and a Fashioner who has created the cosmos and all that exists. Then there is neither purpose nor an ultimate destiny for existent things. In such a cul-de-sac, we have exhausted all means to penetrate the veil and there are no paths leading from the eyes which can see ice floating over water, to the hearts which have the capacity to take that observation as the starting point for gnosis. *Have they not travelled on Earth that their hearts might understand and their ears might listen! Surely, it is not the eyes that are blinded, but the hearts in the breasts that are rendered blind* (*al-Ḥajj:* 47).

Wa'Llāhu'l-mustaʿān, wa mā tawfīqī illā bi'-Llāh

Wuddistān

22 Jumādī I, 1430/May 17, 2009