

Why does ice float?

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An ice cube floats in a glass of water even though it consists of the same substance that surrounds it. Almost all of it is submerged, with a small part sticking out. The short answer is that ordinary ice is less dense than liquid water. But that sentence leaves two questions: why density determines where the cube comes to rest, and why freezing water changes its density in that direction.

The scene needs to be specified. We mean ordinary water ice, without large air pockets, in fresh water near freezing and at atmospheric pressure. We are not claiming that every solid called ice floats in every liquid or under every pressure.

1. What we are comparing

Density is mass divided by volume: $\rho = m/V$. Comparing densities means comparing how much mass occupies equal volumes. A mountain of ice can have much more mass than the water in a glass and still have lower density. "It weighs less" is insufficient unless we specify the quantities being compared.

We can also follow the same quantity of water before and after freezing. Without loss of matter, its mass is effectively conserved at the precision of this everyday experiment. If its volume increases, its density decreases. The cube does not need to lose water to become less dense. Nor does it need to fill with bubbles: these can change a sample's density, but ordinary ice does not need them to float.

Properties depend on conditions. The IAPWS reference formulation for hexagonal ice gives approximately 916.72 kg/m^3 at its normal-pressure melting point [1, Table 6]. Liquid water near freezing has a density close to 1000 kg/m^3 [2]. For the simple calculations below, we will use 917 and 1000 kg/m^3 . These are rounded values, not universal constants or a pair of new measurements.

2. Why density becomes flotation

A liquid at rest exerts pressure on the surface of an immersed object. Pressure increases with depth. Summing the forces over the whole surface produces an upward buoyant force equal to the weight of displaced liquid. This is the hydrostatic form of Archimedes' principle.

If the total ice volume is V and the submerged volume is V_s , its weight is $\rho_i V g$ and the buoyant force is $\rho_l V_s g$. Subscripts i and l denote ice and liquid; g is gravitational acceleration. At equilibrium, neglecting air buoyancy and capillary forces:

$$\rho_l V_s g = \rho_i V g; \text{ therefore, } V_s/V = \rho_i/\rho_l.$$

With the rounded values, $V_s/V = 917/1000 = 0.917$. Approximately 92% of the volume is submerged and 8% emerges. This is a statement about volume, not height. An irregular piece can project a considerable distance above the surface while almost all its volume remains underwater.

If we push a freely floating piece slightly downwards, it displaces more liquid while its weight barely changes. The additional buoyancy favours its return upwards. If we lift it slightly, it displaces less liquid and its weight favours descent. This argument explains

vertical equilibrium; it does not by itself determine the stable orientation of an irregular piece.

A fully submerged piece denser than the liquid cannot be supported by that buoyant force alone. A less dense piece, by contrast, can balance its weight before becoming completely submerged. For small bodies or objects subject to other forces, the model needs extending. A free ice cube is a good approximation, but that does not make every object remaining at the surface evidence of lower density.

3. What changes between the molecules

Water molecules do not turn into another substance when they freeze. Their organisation changes. In ordinary hexagonal ice, hydrogen bonds favour an open network with approximately tetrahedral coordination: each molecule has four bonded neighbours in that arrangement. It provides more volume per molecule than the liquid near melting [3].

“Open” describes molecular organisation. It does not mean the crystal is a sponge with air-filled cavities. Lower density belongs to the structure of ice even without visible bubbles.

The liquid also has hydrogen bonds. It is neither a collection of completely independent molecules nor a rigid copy of the crystal. Its organisation continually rearranges and allows more compact average packing. A more ordered solid need not occupy less volume: order and density are different properties [3].

This description explains the direction of the change, but a drawing of tetrahedra does not calculate a precise density by itself. That requires distances, three-dimensional organisation and thermodynamic conditions. The molecular model and measured density must agree quantitatively; an appealing picture cannot replace that test.

4. How we know the structure

There are two different lines of evidence. Measuring mass and volume determines density. Observing flotation tests the mechanical consequence. Neither operation alone reveals how atoms are arranged inside the crystal.

Diffraction supplies structural information. Researchers measure how a crystal scatters radiation or particles and compare the intensities with those predicted by models of atomic positions. Structure is inferred from those patterns; the result is not an ordinary photograph of little balls joined by rods.

A study by Chodkiewicz and colleagues using electron diffraction of hexagonal ice illustrates why this distinction matters. The authors compared structural refinement methods and found that the treatment of multiple scattering affected the accuracy of the resulting O-H distances [4]. This is uncertainty in details of reconstruction, not a refutation of the crystal's existence or lower density.

Agreement between methods does not require every method to have the same sensitivity to the same atoms. Nor does an average structure describe every instantaneous motion. We can have strong evidence for a crystalline arrangement while continuing to improve the precision of its details.

5. What we can calculate and what we cannot

The flotation balance provides another check. With the same rounded values, one kilogram of liquid water occupies one litre, whereas one kilogram of ice occupies approximately 1.09 litres. The volume increase is around 9%. That expansion and the emerged fraction, close to 8%, are not the same percentage: their denominators differ.

For expansion, we compare the increase with the original liquid volume: $1000/917 - 1 \approx 0.091$. For the emerged part, we compare with the total ice volume: $1 - 917/1000 = 0.083$. Confusing the questions can produce similar numbers with incorrect explanations.

We can also predict what happens in an ideal container. Pure ice floating in pure water already displaces a mass of water equal to its own. After melting, that same mass occupies the volume previously displaced. The level stays unchanged within this model, provided there are no losses and we compare at the same final liquid density. Warming of the system, salts or trapped materials require corrections. The argument does not transfer unchanged to ice supported on land that subsequently enters the water.

6. Where the everyday answer ends

Water has other solid phases. Sufficient changes in pressure and temperature can favour ice structures denser than the ordinary form [3]. A tetrahedral drawing must not become a prohibition on every other arrangement. Deciding which phase exists and whether it would float requires its stability conditions and the density of the particular liquid with which it is compared.

Nor can we simply transfer the calculated percentage to salt water or a sample containing air, salts or sediment. The criterion remains the balance between weight and buoyancy, but the inputs change. An example's limitations do not invalidate the law; they delimit its application.

The answer to the title therefore has two connected levels. Ordinary ice floats because it displaces enough water to support its weight before becoming completely submerged. That is possible because its molecular organisation makes it less dense than liquid water near melting. The first explanation is mechanical; the second connects that mechanics to matter. Neither requires cold to weigh less or every solid to behave alike.

Related reading

QTC-003 develops the general question of solidity. It is optional associated reading; the specific problem here is relative density and flotation equilibrium.

References

- [1] IAPWS. Revised Release on the Equation of State 2006 for H₂O Ice Ih. R10-06(2009), September 2009. <https://iapws.org/technical-guidance/release/Ice-2009>
- [2] IAPWS. Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use. R6-95(2018), September 2018. <https://iapws.org/documents/release/IAPWS-95.download>
- [3] Brini, E. et al. How Water's Properties Are Encoded in Its Molecular Structure and Energies. Chemical Reviews 117, 12385–12414 (2017). <https://doi.org/10.1021/acs.chemrev.7b00259>
- [4] Chodkiewicz, M. L. et al. Hirshfeld atom refinement and dynamical refinement of hexagonal ice structure from electron diffraction data. IUCrJ 11, 730–736 (2024). <https://doi.org/10.1107/S2052252524006808>