**THE STRUCTURE OF WATER**

**and**

**HOW PSYCHE ENTERS MATTER**

**Part 3:**

**The Many Phases of Water**

***by***

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**Part 3: The Many Phases of Water**

**The Phases of Matter**

In the [physical sciences](https://en.wikipedia.org/wiki/Outline_of_physical_science), a *phase* is a region of space (a [thermodynamic system](https://en.wikipedia.org/wiki/Thermodynamic_system)), throughout which all physical properties of a material are essentially uniform.Examples of physical properties include [density](https://en.wikipedia.org/wiki/Density), [index of refraction](https://en.wikipedia.org/wiki/Refractive_index), [magnetization](https://en.wikipedia.org/wiki/Magnetization) and chemical composition.

A simple description is that a phase is a region of material that is chemically uniform, physically distinct, and (often) mechanically separable. In a system consisting of ice and water in a glass jar, the ice cubes are one phase, the water is a second phase, and the humid air over the water is a third phase. The glass of the jar is another separate phase.



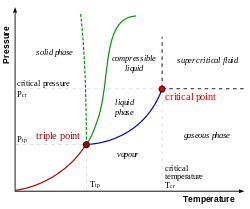
**Figure 1: A Basic Snowflake Structure**

The term *phase* is sometimes used as a synonym for [state of matter](https://en.wikipedia.org/wiki/State_of_matter), but there can be several [immiscible](https://en.wikipedia.org/wiki/Miscibility) phases of the same state of matter. Also, the term *phase* is sometimes used to refer to a set of equilibrium states demarcated in terms of state variables such as pressure and temperature by a [phase boundary](https://en.wikipedia.org/wiki/Phase_boundary) on a [phase diagram](https://en.wikipedia.org/wiki/Phase_diagram).

Because phase boundaries relate to changes in the organization of matter, such as a change from liquid to solid or a more subtle change from one crystal structure to another, this latter usage is similar to the use of "phase" as a synonym for state of matter.

However, the state of matter and phase diagram usages are not commensurate with the formal definition given above, and the intended meaning must be determined in part from the context in which the term is used.

**The Phase Diagram -** A phase diagram in [physical chemistry](https://en.wikipedia.org/wiki/Physical_chemistry), [engineering](https://en.wikipedia.org/wiki/Engineering), [mineralogy](https://en.wikipedia.org/wiki/Mineralogy), and [materials science](https://en.wikipedia.org/wiki/Materials_science) is a type of [chart](https://en.wikipedia.org/wiki/Chart) used to show conditions at which thermodynamically distinct [phases](https://en.wikipedia.org/wiki/Phase_(matter)) can occur at [equilibrium](https://en.wikipedia.org/wiki/Thermodynamic_equilibrium).



**Figure 2: Basic Phase Diagram**

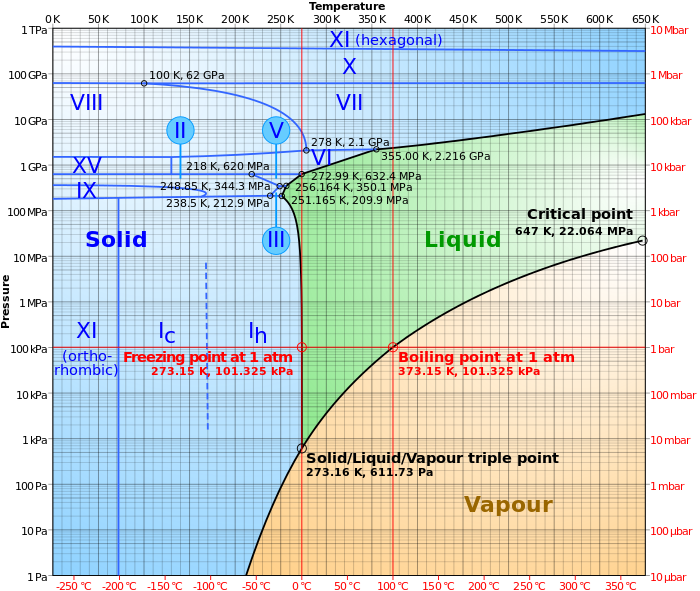
These diagrams show the preferred physical states of matter at different temperatures and pressures. Within each phase, the material is uniform with respect to its chemical composition and physical state. At typical temperatures and pressures (on Earth), water is a liquid, but it becomes solid (that is, ice) if its temperature is lowered below 273°K (0°C, 32°F) and gaseous (that is, water vapor) if its temperature is raised above 373°K (100°C, 212°F), at the same pressure.

Each line on a phase diagram (“phase line”) represents a phase boundary and indicates the conditions under which two phases may stably coexist in any relative proportions (having the same Gibbs free energy). Here, a slight change in temperature or pressure may cause the phases to abruptly change from one physical state to the other.

Where three phase lines join, there is a “triple point” when three phases stably coexist (having identical Gibbs free energies),but may abruptly and totally change into each other given a slight change in temperature or pressure. Under the singular conditions of temperature and pressure where liquid water, gaseous water and hexagonal ice stably coexist (at its triple point), the boiling point of water and melting point of ice are equal.

A “critical point” occurs at the end of a phase line where the properties of the two phases become indistinguishable from each other. For example, when water is at specific singular conditions of temperature and pressure, liquid water is hot enough and gaseous water is under sufficient pressure that their densities are identical.

At temperatures above the critical temperature, a gas cannot be liquefied. Critical points are usually found at the high temperature end of the liquid-gas phase line. Notice on the following diagram how many different phases of ice are found in nature!



**Figure 3: Phase Diagram for Water**

**The Crystalline Structures of Ice**

Ice can assume a large number of different crystalline structures, more than any other known material. At ordinary pressures the stable phase of ice is called “ice I,” and the various high-pressure phases of ice number up to ice XIV so far. At this time, there are 18 known different phases of ice.

There are two closely related variants of ice I: hexagonal ice Ih (*pronounced: ice one h, also known as ice-phase-one*), which has hexagonal symmetry, and cubic ice Ic, which has a crystal structure similar to diamond. Ice Ih is the normal form of ice, or frozen water.[[1]](https://en.wikipedia.org/wiki/Ice_Ih" \l "cite_note-1) Ice Ic is formed by depositing water vapor at very low temperatures (below 140°K). Amorphous ice can be made by depositing water vapor onto a substrate at still lower temperatures.

Virtually all ice in the [biosphere](https://en.wikipedia.org/wiki/Biosphere) is ice Ih, with the exception only of a small amount of [ice Ic](https://en.wikipedia.org/wiki/Ice_Ic) that is occasionally present in the upper atmosphere. Ice Ih exhibits many peculiar properties that are relevant to the existence of life and regulation of global climate.[[2]](https://en.wikipedia.org/wiki/Ice_Ih" \l "cite_note-2) Ice Ih is stable down to -200°C (73°K, -328°F) and can exist at pressures up to 0.2 [GPa](https://en.wikipedia.org/wiki/Pascal_(unit)). The crystal structure is characterized by [hexagonal symmetry](https://en.wikipedia.org/wiki/Hexagonal_(crystal_system)) and near [tetrahedral](https://en.wikipedia.org/wiki/Tetrahedral) bonding angles.

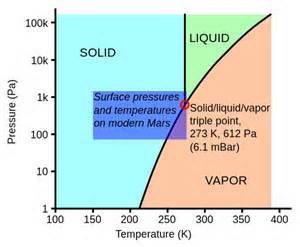
Each oxygen atom inside the ice Ih lattice is surrounded by four other oxygen atoms in a tetrahedral arrangement. The distance between oxygens is approximately 2.75 Angstroms. The hydrogen atoms in ice are arranged according to Bernal-Fowler rules:

1) two protons are close (about 0.98A) to each oxygen atom, much like in a free water molecule;

2) each H20 molecule is oriented so that the two protons point toward two adjacent oxygen atoms;

3) there is only one proton between two adjacent oxygen atoms;

4) under ordinary conditions, any of the large number of possible configurations is equally probable.



**Figure 4: Phase Diagram for Water on Mars**

**Ice 1X**

Ice-nine is a fictional material appearing in Kurt Vonnegut's novel *Cat's Cradle*. Ice-nine is supposedly a polymorph of water (invented by Dr. Felix Hoenikker[1]). It is more stable than common ice (Ice Ih); instead of melting at 0 °C (32 °F), it melts at 45.8 °C (114.4 °F).

When ice-nine comes into contact with liquid water below 45.8 °C (thus effectively becoming supercooled), it acts as a seed crystal and causes the entire body of water to solidify, which quickly crystallizes as more ice-nine. As people are mostly water, ice-nine kills nearly instantly when ingested or brought into contact with soft tissues exposed to the bloodstream, such as the eyes.

In the story, ice-nine is developed by the Manhattan Project in order for the Marines to no longer need to deal with mud, but abandoned when it becomes clear that any quantity of it would have the power to destroy all life on earth. A global catastrophe involving freezing the world's oceans with ice-nine is used as a plot device in Vonnegut's novel.



**Figure 5: Formation of Ice 9**

**Coming Next:**

**Part 4: The Formation of the 4th Phase of Water**

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