PHASE PROPERTIES AND TYPE OF EARTH'S WATER ICE AND SPACE ICES

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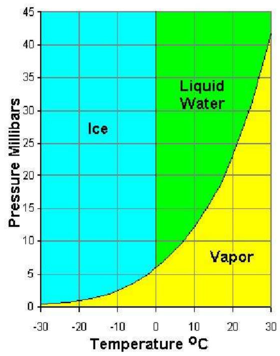
Introduction: Ice is the name given to any one of the 15 known crystalline solid phases of water. In non-scientific contexts, it usually describes ice I_h, which is the most abundant of these phases. It can appear transparent or an opaque bluish-white color depending on the presence of impurities such as air. The addition of other materials such as soil may further alter appearance [1]. The most common phase transition to ice I_h occurs when liquid water is cooled below 0 °C (273.15 K, 32 °F) at standard atmospheric pressure. It can also deposit from a vapor with no intervening liquid phase, such as in the formation of frost. Ice appears in nature in varied forms such as hail and glaciers. Amorphous ice is more common in outer space whereas hexagonal crystalline ice is extremely rare, which is predominant on Earth [6].

Phase properties of Earth's Water Ice: The main physical nature and phases of water ice are given in the table 1. The figure 1 a) and b) shows the phase diagram of water and different ice types.

Table 1: Phases and characteristics of Water Ice [6]

Phase	Characteristics
Amorphous ice	Amorphous ice as an ice which does not have crystal structure. This ice occurs in three forms; low density (LDA) formed at atmospheric pressure, or below, high density (HDA) and very high density amorphous ice (VHDA), forming at higher pressures. LDA forms by extremely quick cooling of liquid water ("hyperquenched glassy water", HGW), by depositing water vapour on very cold substrates ("amorphous solid water", ASW) or by heating high density forms of ice at ambient pressure.
Ice I_h	Normal hexagonal crystalline ice. Almost all ice in the Earth's biosphere is ice I_h with small amount of I_c
Ice I_c	Metastable cubic crystalline variant of ice. The oxygen atoms are arranged in a diamond structure, made at 130-150 K, and is stable upto 200K, when it transform to ice I_h. It is sometimes present in the upper atmosphere.
Ice 2	A rhombohedral crystalline form with highly ordered structure. Formed from ice I_h by compressing it at temperature of 190-210 K. When heated it undergoes transformation to ice 3.
Ice 3	A tetragonal crystalline ice, formed by cooling water down to 250 K a 300 MPa, least dense of the high pressure phases and denser than the water.
Ice 4	Metastable rhombohedral phase. Does not easily form without a nucleating agent.
Ice 5	A monoclinic crystalline phase, formed by cooling water to 253 K at 500 MPa. Most complicated structure of all.
Ice 6	A tetragonal crystalline phase, formed by cooling water to 270 K at 1.1 GPa, shows Debye relaxation.
Ice 7	A cubic phase. The hydrogen atom's position is disordered, the material shows Debye relaxation. The hydrogen bonds from two interpenetrating lattices.
Ice 8	A more ordered version of Ice 7, where the hydrogen atoms assume fixed positions, formed from ice 7 by cooling it beyond 5°C.
Ice 9	A tetragonal metastable phase, formed gradually from ice 3 by cooling it from 208 K to 165 K, stable below 140 K and pressures between 200 and 400 MPa. It has density of 1.16 g/cm^3, slightly higher than ordinary ice.
Ice 10	Proton ordered symmetric ice, forms at about 70 GPa.
Ice 11	An orthorhombic low temperature equilibrium form of hexagonal ice, which is ferroelectric.
Ice 12	A tetragonal metastable dense crystalline phase. it is observed in the phase space of ice V and ice VI. It can be prepared by heating high-density amorphous ice from 77 K to about 183 K at 810 MPa
Ice 13	A monoclinic crystalline phase, formed by cooling water below 130 K at 500 MPa. The proton-ordered from of ice 5.
Ice 14	An orthorhombic crystalline phase, formed below 118 K at 1.2 GPa. The proton-ordered from of ice 12.
Ice 15	The predicted but no proven proton ordered form of ice 6, thought to be formed by cooling water to around 108-80 K at 1.1 Gpa

Space Ice: The solid-vapor curve becomes very low (fig. 1a) [3] as pressures and temperatures decreases and by -90°C the vapor pressure of ice is about 10^{-4} mb. At the temperatures of the outer solar system, the vapor pressure of ice is so low that ice remains for geologically long times even in a vacuum. In Space, instead of pure water



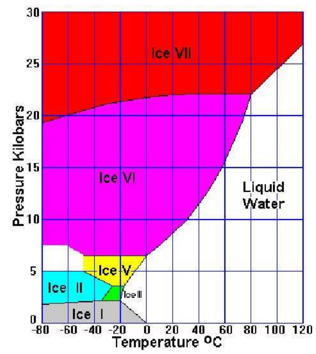


Fig. 1a): Phase diagram of water and **Fig. 1b):** Phase diagram of Ice (source: Steven Dutch)

ice, we find *Clathrate Hydrates,* which were first discovered in 1810 by Sir Humphrey Davy, they are crystalline water based solids physically resembling ice, in which small non polar molecules are trapped inside *cages* of hydrogen bonded water molecules. These gases includes O_2, H_2, N_2, CO_2, CH_4, H_2S, Ar, Kr, and Xe as well as some higher hydrocarbons and freons which forms hydrates at suitable temperatures and pressures [6].

Fig. 2a): Glacier's Dense Black Ice (source: Praveen Thakur)

Fig. 2b): White Ice, Snow & Water (source: Praveen Thakur)

Fig. 2c): Blue Ice, Snow at Antarctica (source: Bangor Uv.)

The fig.2 a), 2b) and 2c) shows the Earth's Black glacier ice, lake white ice, snow, water and blue ice of Antarctica. The absorbance spectra of the 3, 6 and 12-μm features of amorphous and crystalline H_2O ice between 10 and 140 K has shown that the ice undergoes an amorphous-to-crystalline phase transition in the 110–120 K range [5].

Remote Sensing of Water Ice and Space Ice: The ice in space may occurs in form of dry ice at Mars polar caps [2] [7], clathrate hydrate, Earth moon poles, Europa, and Triton are other examples where ice is found and has been studied using remote sensing based observations. The CO_2, SO_2, and H_2S, other than the water ice, have been detected on the surface of Europa by spectroscopic sensors. These substances might occur as pure crystalline ices, as vitreous mixtures, or as clathrate hydrate phases, depending on the system conditions and the history of the material [4]. Similar ice types are found on the Saturn's icy moons by Cassini Team [8].

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