

# Water, Steam, and Ice

Turn off all electronic devices

## Observations about Water, Steam, and Ice

Water has three forms or phases  
Ice is common below 32 °F (0 °C)  
Water is common above 32 °F (0 °C)  
Steam is common at high temperatures  
The three phases sometimes coexist

## 4 Questions about Water, Steam, Ice

1. How can water and ice coexist in a glass?
2. Can steam exist below 212 °F (100 °C)?
3. Where do ice cubes go in a frostless freezer?
4. Is salt the only chemical that helps melt ice?

## Question 1

Q: How can water and ice coexist in a glass?

A: At 32 °F (0 °C), both phases are stable

Like most chemicals, water has three phases of matter:

- Ice is solid—it has a fixed volume and a fixed shape
- Water is liquid—it has a fixed volume but a variable shape
- Steam or water vapor is gas—it has a variable volume and a variable shape

Ice and water have a special temperature of 32 °F (0 °C)

- Below 32 °F (0 °C), solid ice is the stable phase (water freezes into ice)
- Above 32 °F (0 °C), liquid water is the stable phase (ice melts into water)
- At 32 °F (0 °C), ice and water can coexist

## Phase Equilibrium

When two (or more) phases are present,

- molecules continually shift between the phases
- one phase may grow at the expense of another phase
- such growth often takes or releases thermal energy

At phase equilibrium,

- two (or more) phases coexist indefinitely
- neither phase grows at the expense of the other

## Ice and Water

To melt ice at 32 °F (0 °C), destabilize ice relative to water by

- adding heat
- increasing pressure (ice is very atypical!)

To freeze water at 32 °F (0 °C), stabilize ice relative to water by

- removing heat
- decreasing pressure (water is very atypical!)

Melting ice requires the latent heat of melting

- A mixture of ice and water is slow to change at 32 °F (0 °C)
- At 32 °F (0 °C) and without heat, ice and water can be in phase equilibrium

### Question 2

Q: Can steam exist below 212 °F (100 °C)?

A: Yes, but its pressure is less than atmospheric

Liquid water and gaseous steam

- can coexist over a broad range of temperatures
- but steam density must increase with temperature for phase equilibrium

### Water and Steam

To evaporate water, destabilize water relative to steam by

- adding heat
- reducing the density of the steam

To condense steam, stabilize water relative to steam by

- removing heat
- increasing the density of the steam

Evaporating water requires the latent heat of evaporation

- A mixture of water and steam is slow to change
- In without heat, water and steam can be in phase equilibrium

### Boiling Water and Steam Bubbles

Evaporation can occur at any water/steam interface

- Evaporation can occur into a steam bubble inside water
- If steam bubbles exist and can survive and grow, the water boils
- Rapid evaporation stabilizes the boiling mixture's temperature

Steam bubbles can only survive above a certain temperature

- Pressure in steam bubble depends on steam density and temperature
- Steam density also depends on temperature
- Below a certain temperature, the atmosphere crushes steam bubbles
- At water's boiling temperature, steam bubbles can survive and grow
- Water's boiling temperature depends on the atmospheric pressure

For steam bubbles to exist in the water, they must nucleate

- Steam bubbles nucleate spontaneously in most but not all circumstance.

### Question 3

Q: Where do ice cubes go in a frostless freezer?

A: The ice sublimates directly into steam

Solid ice and gaseous steam

- can coexist over a broad range of temperatures
- but equilibrium steam density rises with temperature

### Ice and Steam

To sublime ice, destabilize ice relative to steam by

- adding heat
- reducing the density of the steam

To deposit steam, stabilize ice relative to steam by

- removing heat
- increasing the density of the steam

Subliming ice requires the latent heats of melting *and* evaporation

### Relative Humidity

Relative humidity measures proximity to phase equilibrium

- At 100% relative humidity, steam and water are in phase equilibrium
- Below 100% relative humidity, water evaporates into steam
- Above 100% relative humidity, steam condenses into water

Below 32 °F (0 °C), ice replaces water as the active phase

- At 100% relative humidity, steam and ice are in phase equilibrium
- Below 100% relative humidity, ice sublimates into steam
- Above 100% relative humidity, steam deposits into ice

At 32 °F (0 °C), water, steam, and ice are all active phases

- At 100% relative humidity, steam, water, and ice are in phase equilibrium

### Question 4

Q: Is salt the only chemical that helps melt ice?

A: No, any chemical that dissolves in water works

Dissolved impurities stabilize liquid water

- reduce ice's melting temperature
- increase water's boiling temperature

Shifts are proportional to solute particle density

Any soluble material can help ice to melt

### Summary about Water, Steam, and Ice

Phase transitions reflect relative phase stabilities

Phases in equilibrium are stable and constant

Temperature and pressure affect phase stabilities

Phase transitions usually take or release heat