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

- Water has three phases: solid, liquid, and gas
- Ice has a melting temperature of 32 °F (0 °C)
  - below which solid ice is the stable phase,
  - above which liquid water is the stable phase,
  - at which ice and water can coexist

Phases of Matter

- Ice is solid: fixed volume and fixed shape
- Water is liquid: fixed volume but variable shape
- Steam is gas: variable volume and variable shape

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
  - that growth often takes or releases thermal energy
- At phase equilibrium,
  - two (or more) phases can 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

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 equilibrium steam density rises with temperature

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

Boiling (Part 1)

- Steam bubbles can form inside water
  - Pressure in steam bubble depends on steam density
- If steam pressure exceeds ambient pressure,
  - steam bubbles can survive and grow via evaporation
- Boiling occurs when bubbles
  - nucleate—when seed bubbles form
  - grow via evaporation
- Need for latent heat stabilizes temperature

Boiling (Part 2)

- Boiling temperature depends on ambient pressure
- Elevated pressure
  - raises water's boiling temperature
  - Some foods cook faster at sea level or below
- Diminished pressure
  - lowers water's boiling temperature
  - Some foods cook slower at high altitudes

Question 3

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

- At 100% relative humidity,
  - steam is in phase equilibrium with water and/or ice
- Below 100% relative humidity,
  - water evaporates and/or ice sublimes
- Above 100% relative humidity,
  - steam condenses as liquid water and/or deposits as ice
- Below 0 °C, ice and steam are active phases
- Above 0 °C, water and steam are active phases
- At 0 °C, water, steam, and ice are all active phases

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