Hewitt/Suchocki/Hewitt

Conceptual Physical Science

Fourth Edition

Chapter 7:

HEAT TRANSFER AND CHANGE OF PHASE

This lecture will help you understand:

- Conduction
- Convection
- Radiation
- Newton’s Law of Cooling
- Global Warming and the Greenhouse Effect
- Heat Transfer and Change of Phase
- Boiling
- Melting and Freezing
- Energy and Change of Phase

Heat Transfer

Processes of thermal energy transfer:

- Conduction
- Convection
- Radiation

Conduction

Conduction

- Transfer of internal energy by electron and molecular collisions within a substance

Heat Transfer: Conduction

Conduction occurs predominately in solids where the molecules remain in relatively restricted locations.

When you stick a nail into ice, does cold flow from the ice to your hand, or heat from your hand to the ice?

Conduction

Insulation

- Doesn't *prevent* the flow of internal energy
- *Slows* the rate at which internal energy flows

Example: Rock wool or fiberglass between walls slows the transfer of internal energy from a warm house to a cool exterior in winter, and the reverse in summer

Conduction Application

- Snow patterns on the roof of a house show areas of conduction and insulation.
- Bare parts show where heat from inside has conducted through the roof and melted the snow.

Heat Transfer: Conduction

Good conductors:

- Composed of atoms with “loose” outer electrons
- Known as poor insulators
- Examples—all metals to varying degrees

Poor conductors:

- Delay the transfer of heat
- Known as good insulators
- Examples—wood, wool, straw, paper, Styrofoam, cork, liquid, gases, air, or materials with trapped air

Conduction

Dramatic example:

Author John Suchocki walks barefoot without burning his feet on red-hot coals,due to poor conduction between the coals and his feet

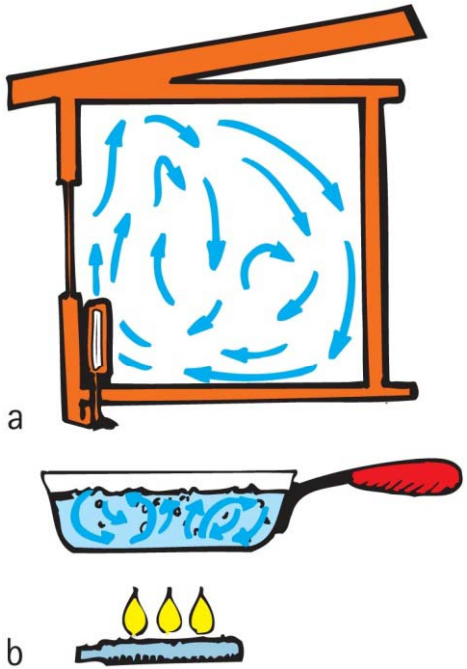
Convection

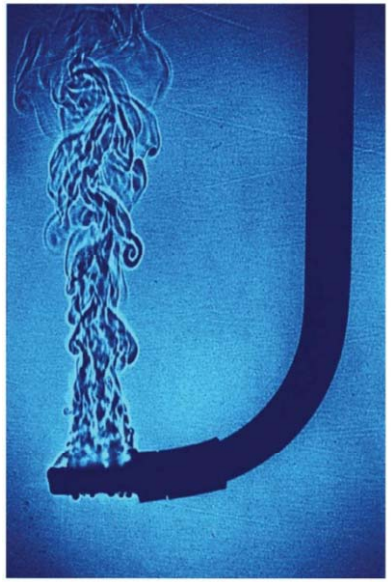
Convection

- Transfer of heat involving only bulk motion of fluids

  Examples:

  - Visible shimmer of air above a hot stove or above asphalt on a hot day
  - Visible shimmers in water due to temperature difference





Convection

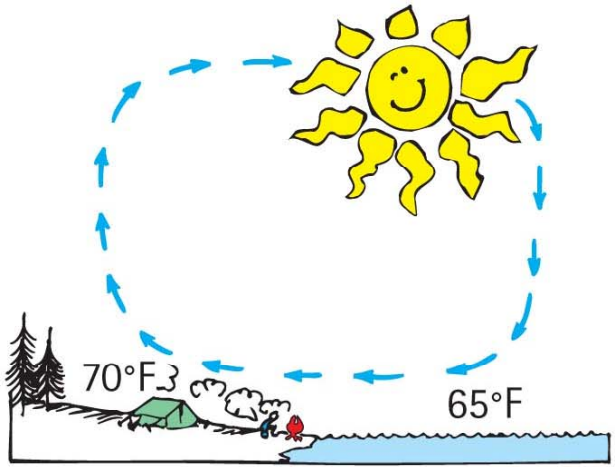
Cooling by expansion

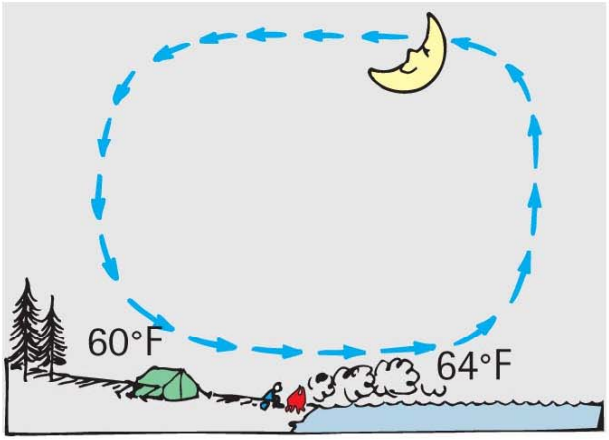
- Opposite to the warming that occurs when air is compressed

Example: The “cloudy” region above hot steam issuing from the nozzle of a pressure cooker is cool to the touch (a combination of air expansion and mixing with cooler surrounding air). Careful, the part at the nozzle that you can’t see is steam—ouch!

Convection Currents

- Convection currents produced by unequal heating of land and water.
- During the day, warm air above the land rises, and cooler air over the water moves in to replace it.
- At night, the direction of air flow is reversed.





Convection

Reason warm air rises

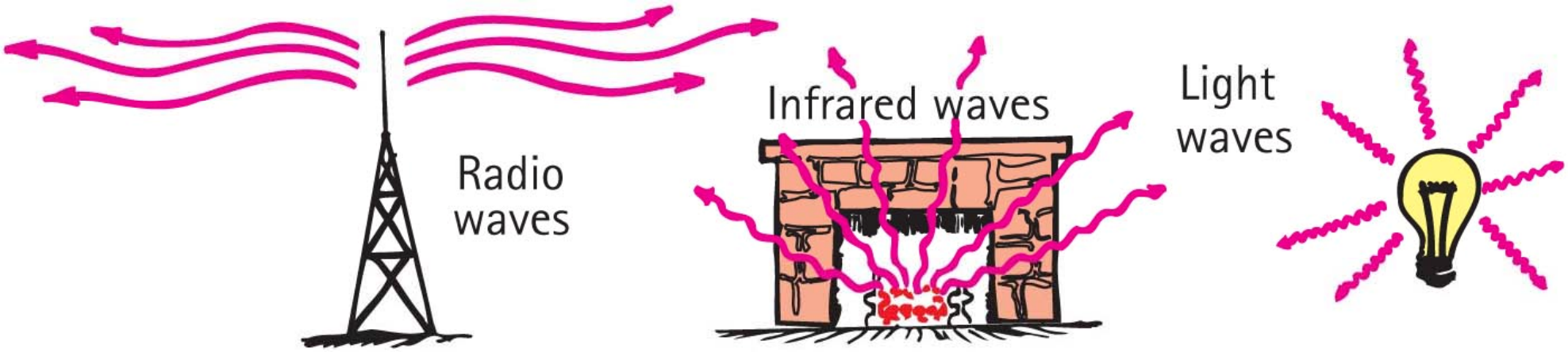
- Warm air expands, becomes less dense, and is buoyed upward
- Air rises until its density equals that of the surrounding air

Example: Smoke from a campfire rises and blends with the surrounding cool air.

Radiation

Radiation

- Transfer of energy via electromagnetic waves that can travel through empty space

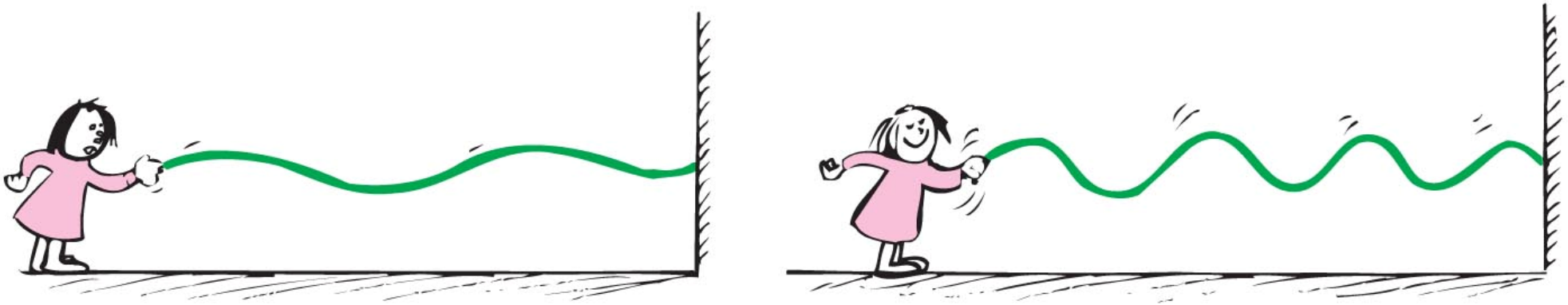


Heat Transfer: Radiation

Wavelength of radiation is related to the frequency of vibration.

Low-frequency vibrations ⇒ long waves

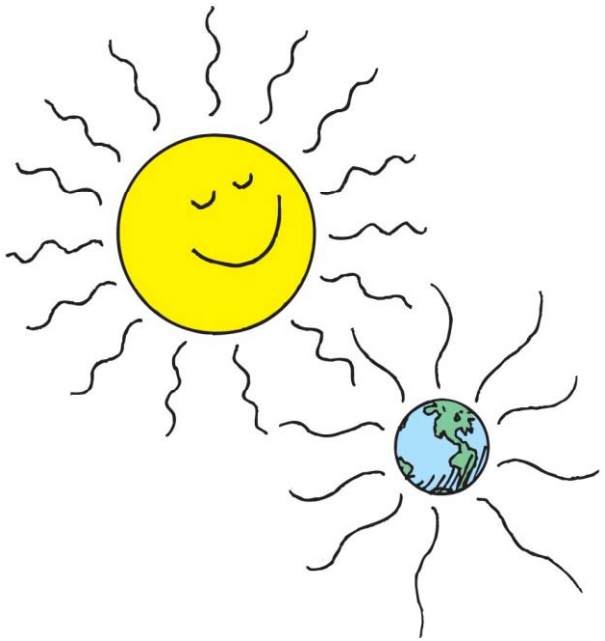
High-frequency vibrations ⇒ short waves



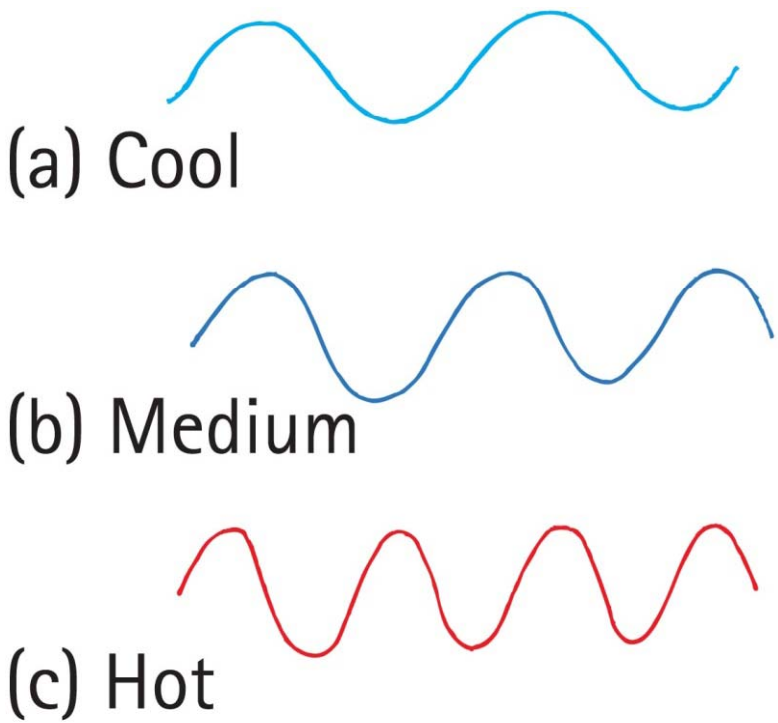
Radiation

Emission of radiant energy

- Every object above absolute zero radiates
- From the Sun's surface comes light, or solar radiation
- From the Earth's surface is terrestrial radiation in the form of infrared waves below our threshold of sight



Wave Frequency - Temperature



(a) A low-temperature (cool) source emits primarily low-frequency, long wavelength waves.

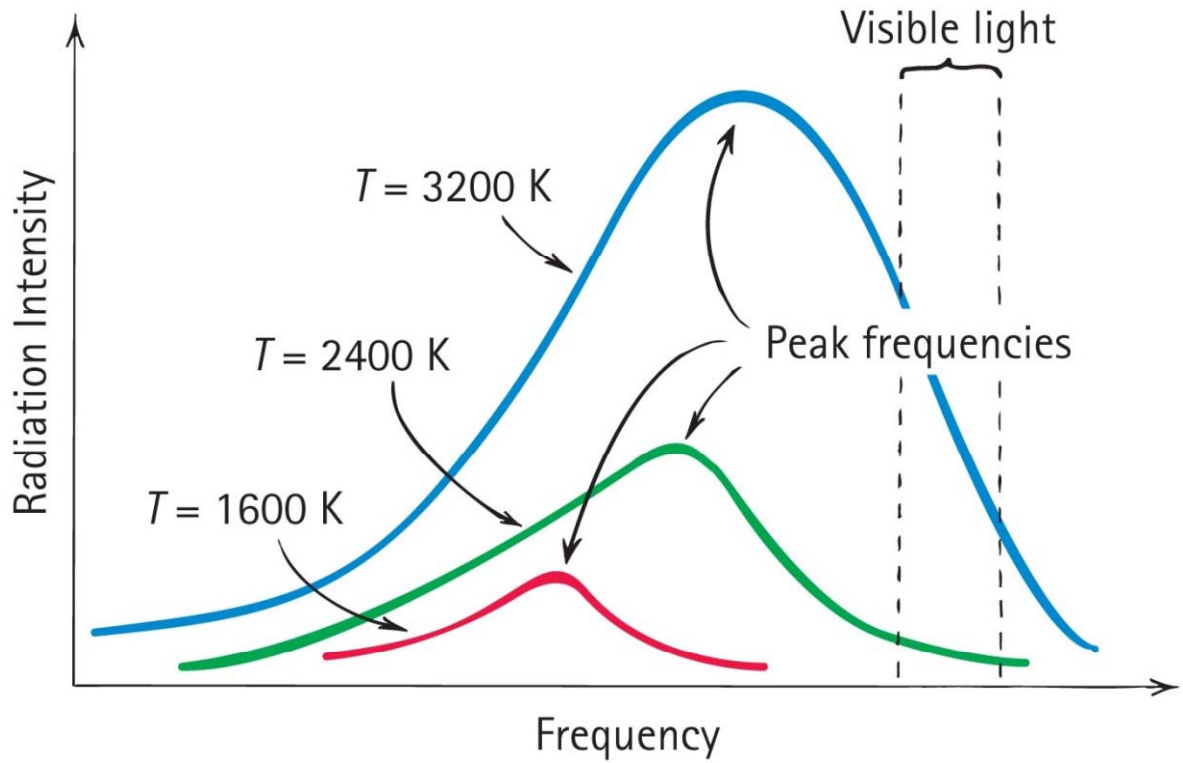
(b) A medium-temperature source emits primarily medium-frequency.

(c) A high-temperature source emits primarily high-frequency, short wavelength waves.

Radiation

Emission of radiant energy

- Peak frequency of radiation is proportional to the absolute temperature of the source ($\bar{f} \sim T$)



Emission and Absorption

The surface of any material both absorbs and emits radiant energy.

When a surface absorbs more energy than it emits, it is a *net absorber*, and temperature tends to rise.

When a surface emits more energy than it absorbs, it is a *net emitter*, and temperature tends to fall.

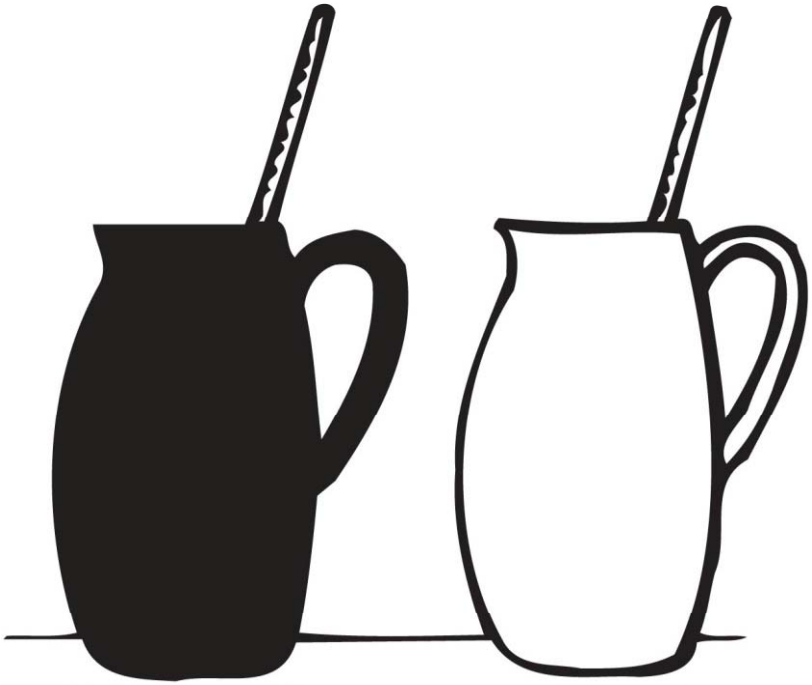
Emission and Absorption

Absorption of Radiant Energy:

The ability of a material to absorb and radiate thermal energy is indicated by its color.

Good absorbers and good emitters are dark in color.

Poor absorbers and poor emitters are reflective or light in color.



Emission and Absorption

Whether a surface is a net absorber or net emitter depends on whether its temperature is above or below that of its surroundings.

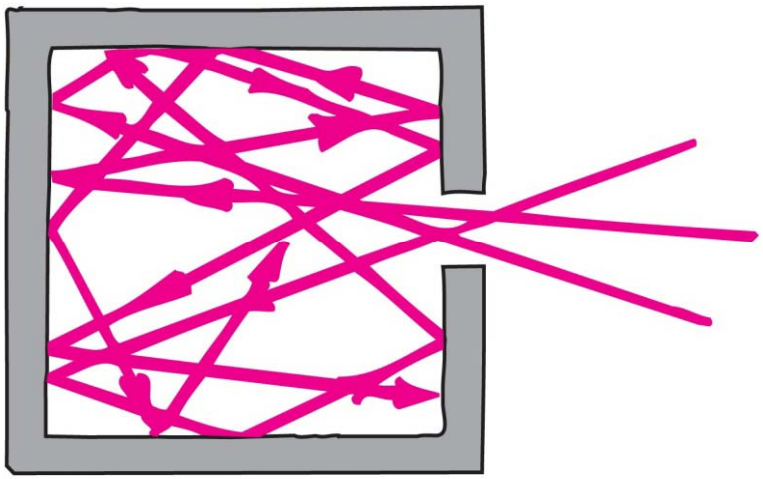
A surface hotter than its surroundings will be a net emitter and tends to cool.

A surface colder than its surroundings will be a net absorber and tends to warm.

Radiation

Reflection of radiant energy

- Darkness is often due to reflection of light back and forth many times partially absorbing with each reflection



- Good reflectors are poor absorbers

Newton's Law of Cooling

Newton's Law of Cooling

- Approximately proportional to the temperature difference ΔT between the object and its surroundings
- In short: Rate of cooling ~ ΔT

  Examples:

  - Hot apple pie cools more quickly in a freezer than if left on the kitchen table
  - Warmer house more quickly leaks thermal energy to the outside than a cooler house

Newton's Law of Cooling

Newton's Law of Cooling (continued)

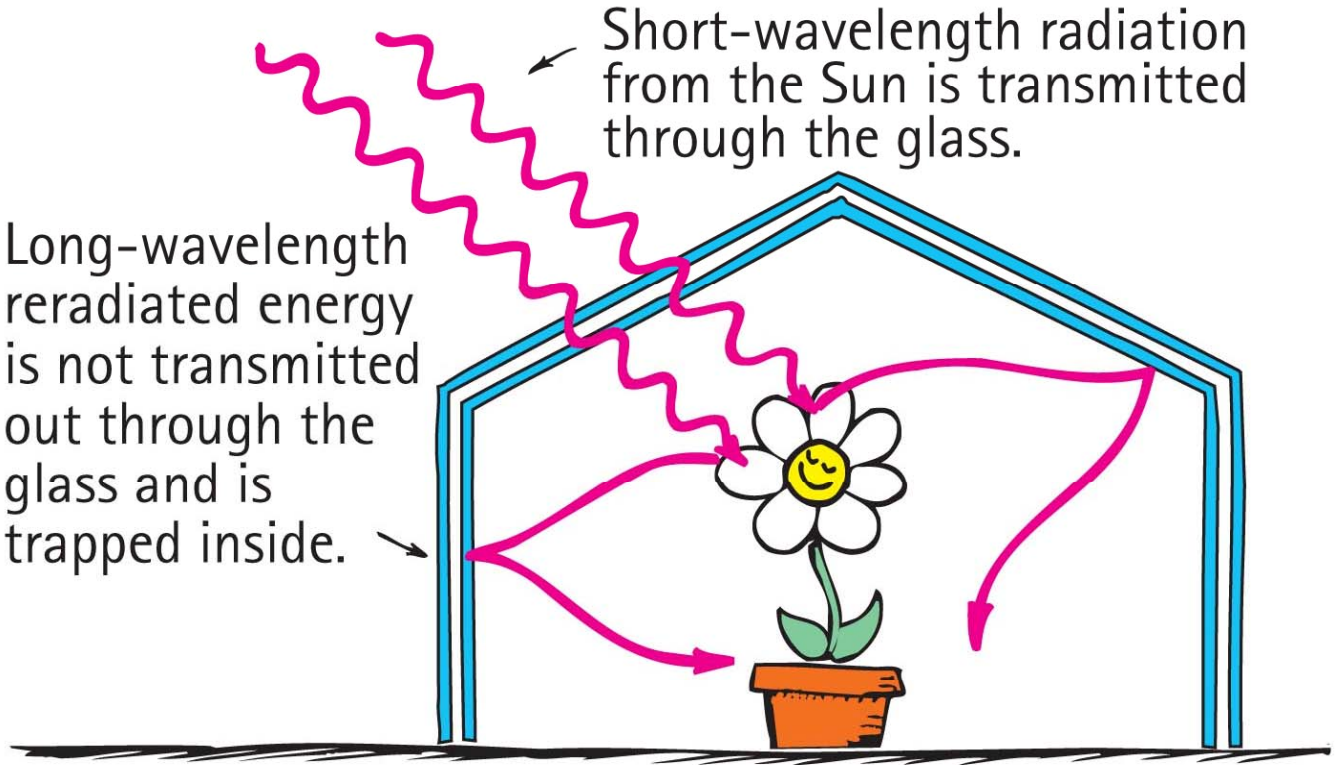
- Applies to rate of warming
  - Object cooler than its surroundings warms up at a rate proportional to ΔT

    Example: Frozen food warm quicker in a warm room than in a cold room

Global Warming and the Greenhouse Effect

Greenhouse Effect

- Named for a similar temperature-raising effect in florists' greenhouses



Global Warming and the Greenhouse Effect

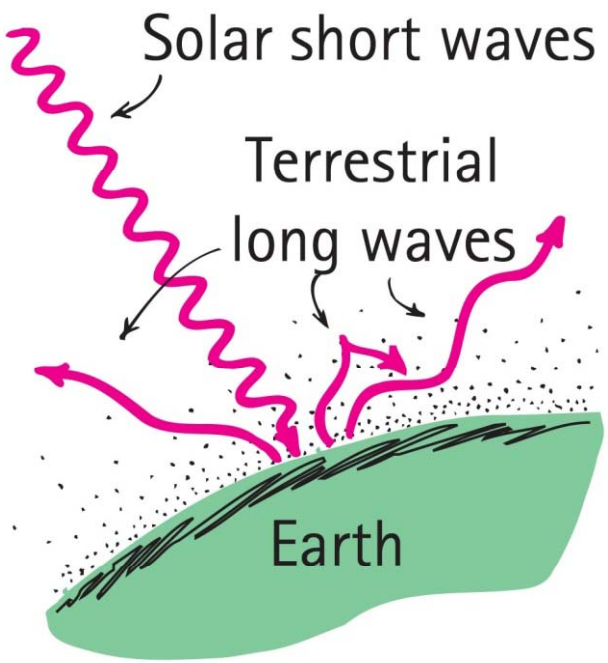
Understanding the greenhouse effect requires two concepts:

- All things radiate at a frequency (and therefore wavelength) that depends on the temperature of the emitting object
- transparency of things depends on the wavelength of radiation

Global Warming and the Greenhouse Effect

Global Warming

- Energy absorbed from the Sun
- Part reradiated by Earth as longer-wavelength terrestrial radiation



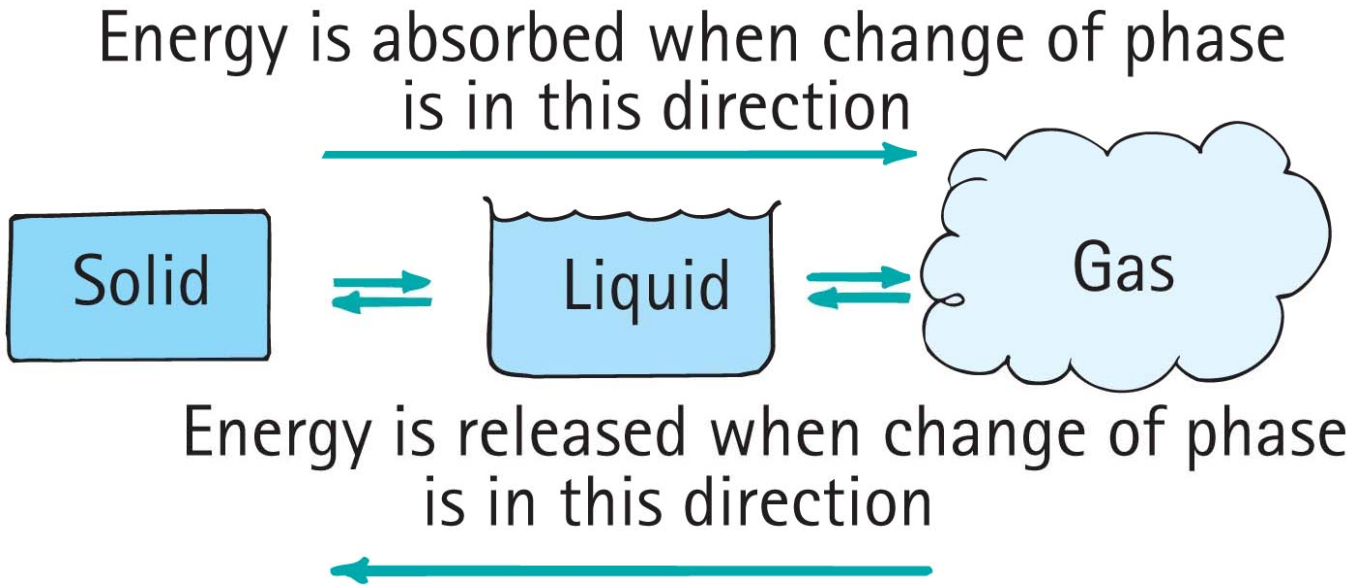
Global Warming and the Greenhouse Effect

Global warming (continued)

- Terrestrial radiation absorbed by atmospheric gases and re-emitted as long-wavelength terrestrial radiation back to Earth
- Reradiated energy unable to escape, so warming of Earth occurs
- Long-term effects on climate are of present concern

Phases of Matter

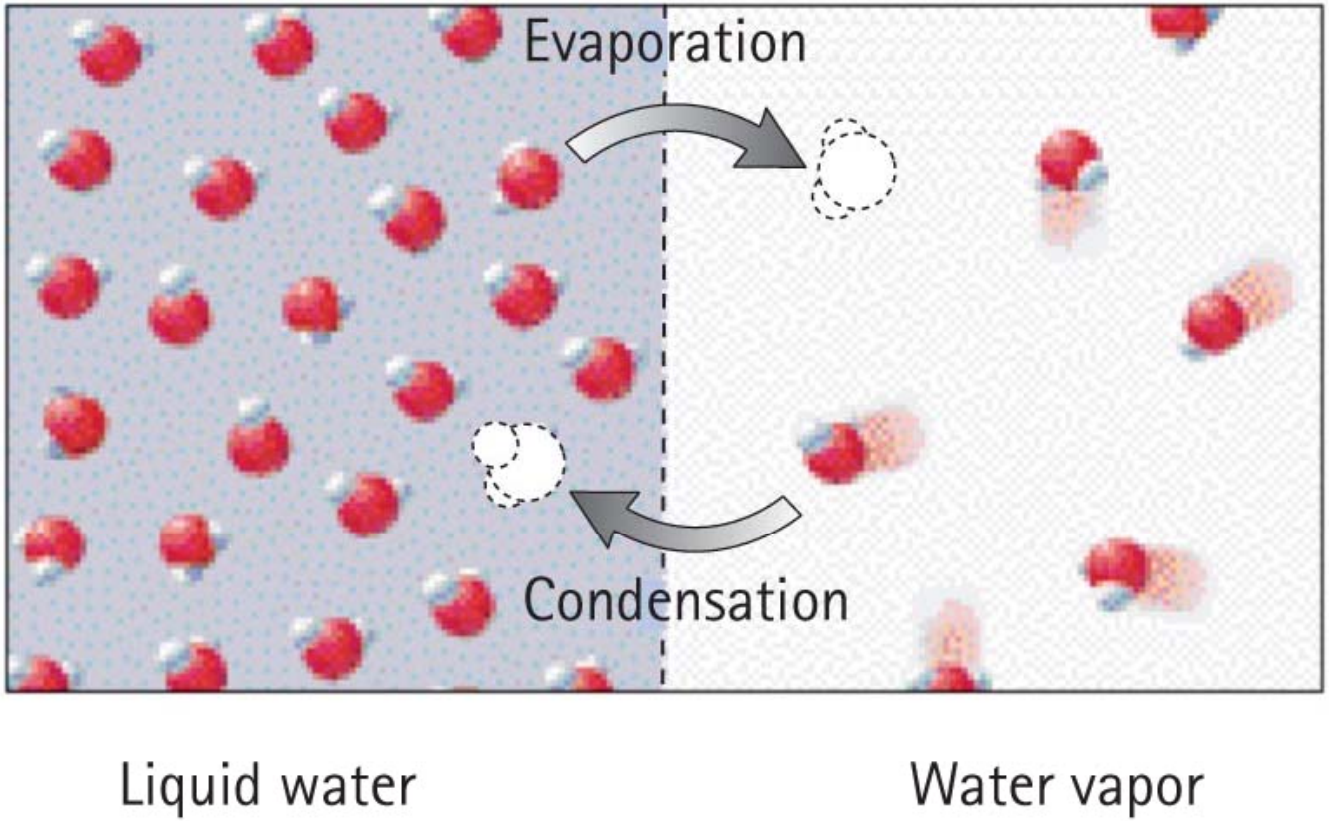
- Matter exists in the three common phases: *solid*, *liquid*, and *gas* (a fourth phase of matter is *plasma*).
- When matter changes from one phase to another, energy is transferred.



Heat Transfer and Change of Phase

Evaporation

- Change of phase from liquid to gas



Heat Transfer and Change of Phase

Evaporation process

- Molecules in liquid move randomly at various speeds, continually colliding with one another
- Some molecules gain kinetic energy while others lose kinetic energy during collision
- Some energetic molecules escape from the liquid and become gas
- Average kinetic energy of the remaining molecules in the liquid decreases, resulting in cooler water

Evaporation Application

- Pigs have no sweat glands and therefore cannot cool by the evaporation of perspiration.
- Instead, they wallow in mud to cool themselves.

Heat Transfer and Change of Phase

Sublimation

- Form of phase change directly from solid to gas

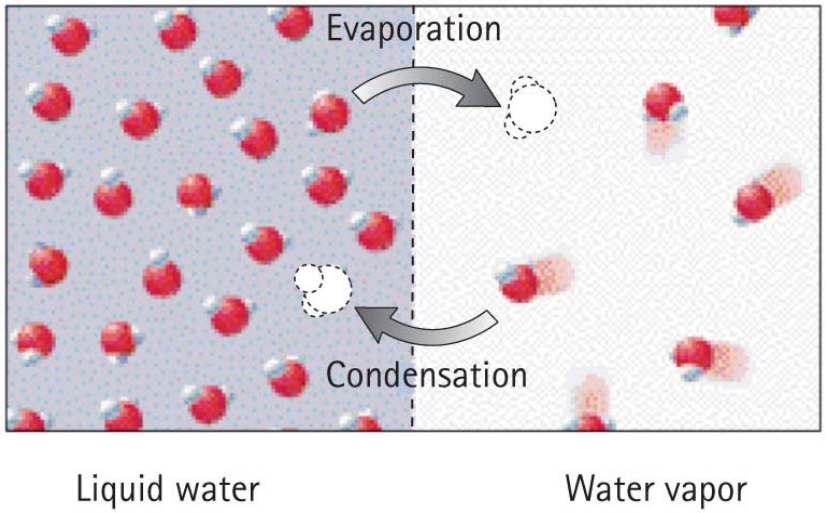
  Examples:

  - dry ice (solid carbon dioxide molecules)
  - mothballs
  - frozen water

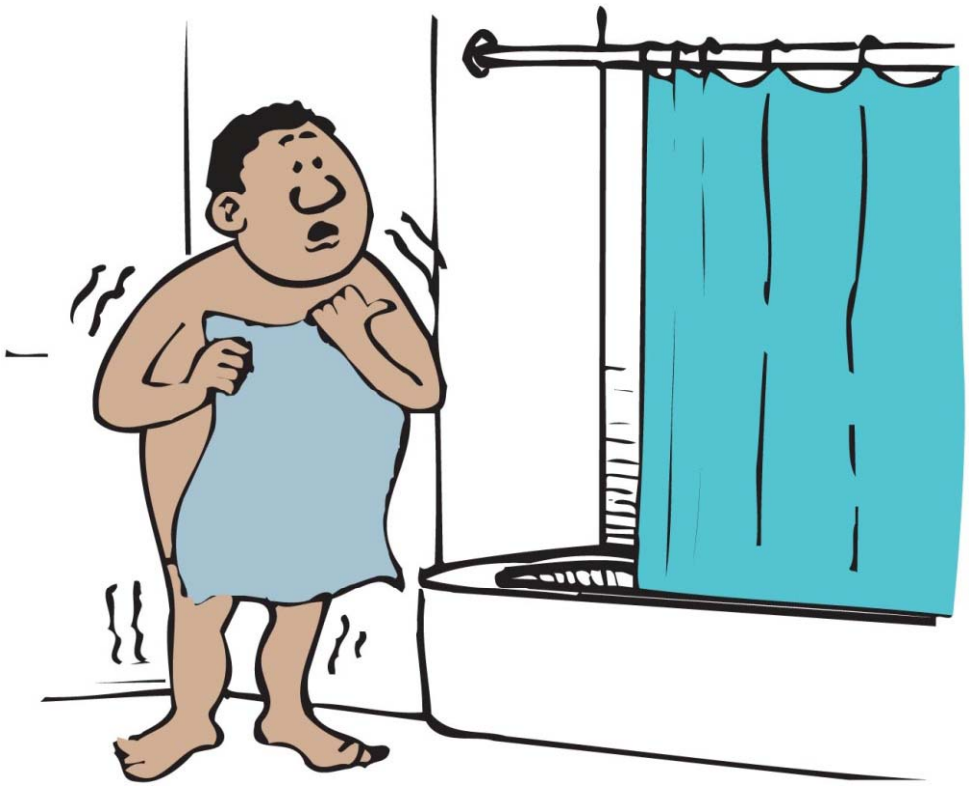
Heat Transfer and Change of Phase

Condensation process

- Opposite of evaporation
- Warming process from a gas to a liquid
- Gas molecules near a liquid surface are attracted to the liquid
- They strike the surface with increased kinetic energy, becoming part of the liquid



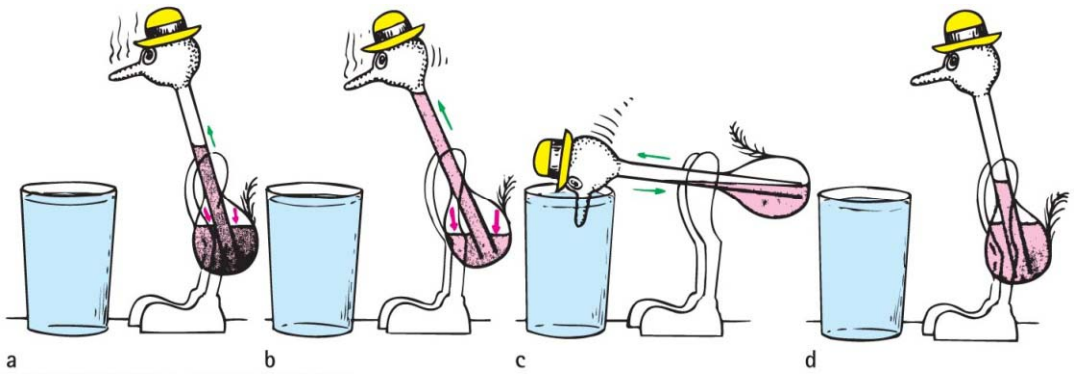
Condensation Application



- If you're chilly outside the shower stall, step back inside and be warmed by the condensation of the excess water vapor in the shower
- Evaporation cools you. Condensation warms you!

Evaporation-Condensation Toy

The toy drinking bird operates by the evaporation of ether inside its body and by the evaporation of water from the outer surface of its head. The lower body contains liquid ether, which evaporates at room temperature.



(a) vaporizes, (b) creates pressure, ether goes up the tube,

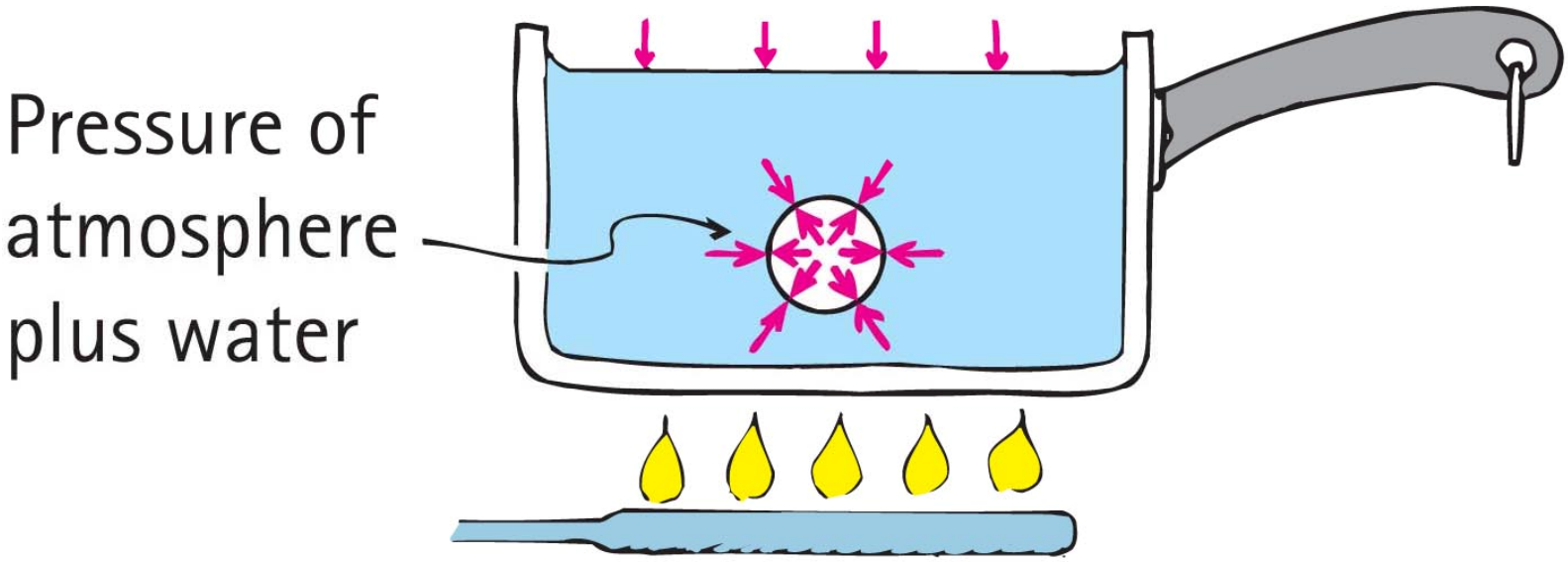
(c) tips over, condensed ether runs back to body.

(d) each pivot wets the head and the cycle repeats.

Boiling

Boiling process

- Rapid evaporation occurs beneath the surface of a liquid

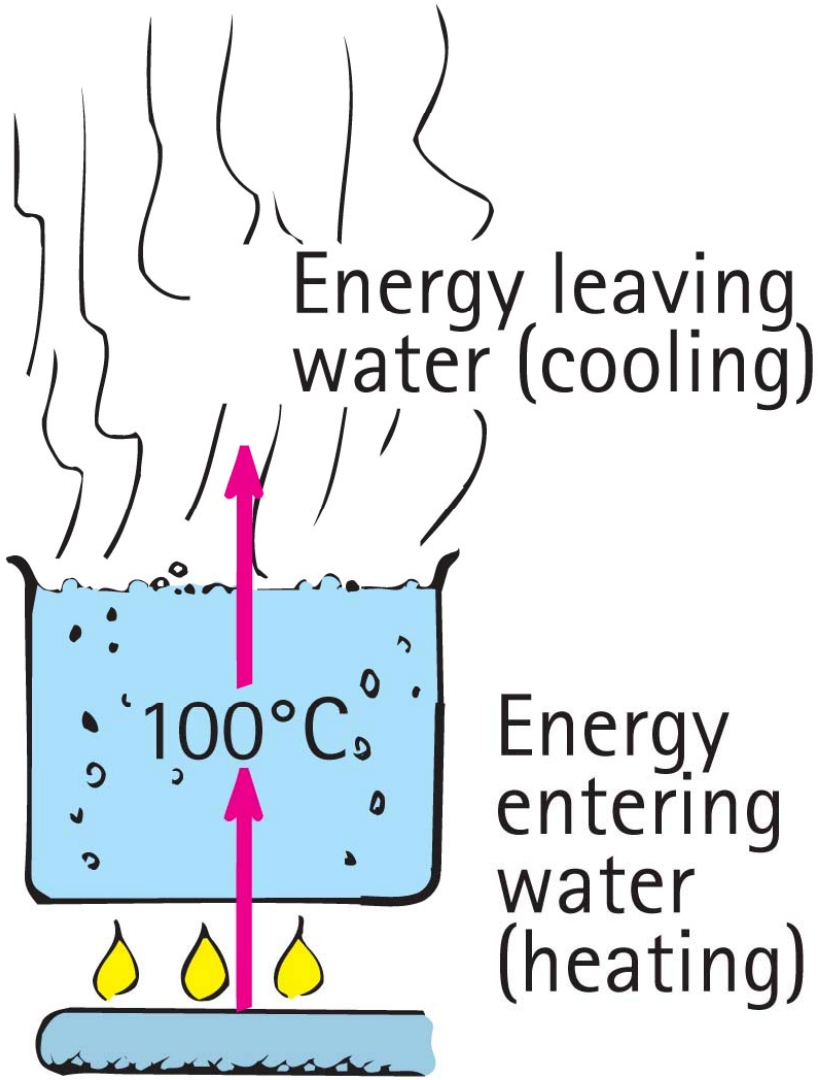


Boiling

Boiling process (continued)

- evaporation beneath the surface forms vapor bubbles
- bubbles rise to the surface
- if vapor pressure in the bubble is less than the surrounding pressure, then the bubbles collapse
- hence, bubbles don’t form at temperatures below boiling point when vapor pressure is insufficient

Boiling



- Heating warms the water from below.
- Boiling cools the water from above.

Pressure Cooker

- The tight lid of a pressure cooker holds pressurized vapor above the water surface, which inhibits boiling.
- In this way, the boiling point of water is greater than 100°C.

Equilibrium

(a) In a mixture of ice and water at 0°C, ice crystals gain and lose water molecules at the same time. The ice and water are in thermal equilibrium.

(b) This gaining-and-losing process is inhibited when salt is added to the water. Then with fewer water molecules at the interface, fewer enter the ice.