Heat Transfer

What are the different ways that heat can move from one place to another?

- Conduction
- Convection
- Radiation

Which method was involved in the class demonstration last Wednesday with the steel balls that dropped as the wax that held them melted?

Conduction

Heat transfer by successive atomic collisions
- Ex. A metal rod held in a fire

Conductors
- Solids built from atoms that have “free” outer electrons
  - Readily transport energy via collisions
  - Ex. Metals

Insulators
- Tightly bound outer electrons
  - Wood, cork, styrofoam, air
  - Air vs. rack in an oven

Convection

Heat transfer due to the actual motion of a fluid
- Operates in liquids and gases
- What causes convection currents?

Convection in the atmosphere drives Earth's weather. It also operates in the interior of the Earth and drives plate tectonics or “continental drift”. Mantle of the Earth is semi-solid rock that supports convection. Plates ride on top of convective cells. Lava flows through cell boundaries. Earth loses internal heat this way.

One cycle takes millions of years => heat loss is extremely slow.
Plates move only a few cm/year.

When plates meet...
1) Head-on collision (Himalayas)
2) "Subduction zone" (one slides under the other) (Andes)
3) "Rift zone" (two plates moving apart) (Mid-Atlantic Ridge)
4) They may just slide past each other (San Andreas Fault)

=> mountain ranges, trenches, earthquakes, volcanoes

The Mid-Atlantic Ridge is a rift zone.
Do you know any other rift zones?

Pangaea Theory: 200 million years ago, all the continents were together!

Radiation
- Energy transmitted in the form of electromagnetic waves
  - A mechanism that can transmit energy across the vacuum of space
    - Conduction – requires collisions in a material object
    - Convection – requires a fluid
  - Ex: Solar energy received by the Earth

Core of the Sun
Temperature: 15 million K \( (1.5 \times 10^7 \text{ K}) \)
Density: 160 gm/cm\(^3\), 160 times that of water, 10 times the density of lead
Let's focus on the core, where the Sun's energy is generated.

Can see rising and falling convection cells \( \Rightarrow \) granulation. Bright granules hotter and rising, dark ones cooler and falling. (Remember convection in Earth's atmosphere, interior and Jupiter).

Why are cooler granules dark? Stefan's Law: brightness \( \propto T^4 \)

Clicker Question:

Earth’s average density is about the same as:
A: water
B: an iron meteorite
C: balsa wood
D: a chunk of volcanic rock

Clicker Question:

Suppose a region of the sun was cooler by a factor of 2 than the average, how would the luminosity compare?
A: 2 times higher
B: 2 times lower
C: 4 times lower
D: 16 times lower
Clicker Question:

What are the main mechanisms of energy transfer in the Sun?
A: radiation, convection
B: radiation, conduction
C: convection, conduction
D: radiation

Changes of Phase

- List the four phases of matter in order of increasing internal energy
  solid => liquid => gas => plasma
- List the processes that take you from a solid to a plasma
  melting => evaporation => ionization
- List the processes that take you from a plasma to a solid
  electron capture => condensation => freezing

Evaporation and Boiling

- Evaporation
  - A phase change from liquid to gas at the surface of a liquid
  - Which molecules are most likely to escape surface?
- Boiling
  - Evaporation beneath the surface of a liquid
  - Vapor pressure must balance surrounding pressure – boiling point
  - How does boiling point change with altitude?
Condensation
- A phase change from a gas to a liquid
  - Opposite of evaporation
- Since evaporation (and boiling) are cooling processes, is condensation a warming process?
  - Yes. Gas molecules near surface of a liquid are attracted to the liquid => collide with greater K.E. => temperature of liquid rises

Water condenses on the outside of a cold soda can and warms the soda in the process.

Sublimation
- A phase change from a solid to a gas (skipping liquid)
- Since evaporation (and boiling) are cooling processes, is sublimation a warming process?
  - No. Energy is given up as the molecules of the solid expand into a gas form.
  - Opposite process is "deposition"

Ex: Chinook winds

DEMO - dry ice

Virga
- Evaporation of precipitation before it gets to the ground

Melting and Freezing
- Melting
  - Random thermal motion at high temp. breaks molecular bonds
- Freezing (reverse process)
  - Decreased motion allows binding due to interparticle attraction
  - Regelation
    - Continued melting and refreezing of water under pressure
      - Ex: Ice skating
      - What special property of water makes this possible?

Regelation – the wire will slowly pass through the ice without cutting it in half.

Ex: Ice skating
- What special property of water makes this possible?
- Density of ice less than that of water => melts under pressure

Regelation – the wire will slowly pass through the ice without cutting it in half.
Clicker Question:

What is the first step to convert a plasma to a solid?
A: ionization
B: freezing
C: condensation
D: electron capture

Clicker Question:

What is it called when water goes directly from a vapor to form ice crystals or frost?
A: sublimation
B: deposition
C: condensation
D: melting

Clicker Question:

Which requires the most energy input?
A: melting ice to make water
B: vaporizing water to make steam
C: sublimating ice to make steam
D: warming water from freezing cold to the boiling point.

Temperature and Phase Changes

- Temperature is constant during a change of phase
  - Absorbed heat goes into breaking molecular bonds $\Rightarrow$ increased potential energy. Translational K.E. remains unchanged. (Left to Right)
  - Extracted heat allows molecular bonds to form (decreased potential energy) at fixed temp. (Right to Left)

A material absorbs energy when melting or vaporizing and expels energy when condensing or freezing.

During a phase change, the energy goes into the change of state rather than into changing the object's temperature.