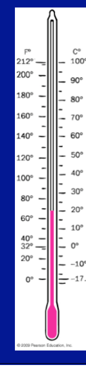
Temperature and Heat

- What is temperature?

How to Measure Temperature?

- Fahrenheit (US) after G.D. Fahrenheit
  - 32°F = freezing
  - 212°F = boiling
- Celsius (rest of world) after A. Celsius
  - 0°C = freezing
  - 100°C = boiling
- C = 5/9 (F - 32) ; or F = 9/5 C + 32
- Kelvin (scientists) after Baron Kelvin
  - 273 K = freezing
  - 373 K = boiling

  K = C + 273



Temperature and Heat

- What is temperature? DEMO
  - A measure of how warm or cold an object is with respect to some standard
  - Related to the random thermal motion of the molecules in a substance
    - Measure of avg. translational kinetic energy of molecules
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Temperature, Heat, and Expansion

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- How are the two concepts related?
  - Heat always flows from hotter to colder objects

Thermal Conductivity

- How fast heat flows through some material.
- carbon = slow
- metal = fast

Japanese Monk fire-walking

DEMO - Thermal Conductivity of Metals

Heat and Internal Energy

- Internal energy
  - Total energy contained in a substance
    - translation, rotational, vibrational kinetic energies
    - interparticle potential energies
  - When an object absorbs (gives off) heat, its internal energy increases (decreases)
- Imagine a red hot thumbtack dropped in a pail of warm water
  - Which has more internal energy?
  - In what direction will heat flow?

Which has more internal energy?

How to Measure Heat?

- SI unit is Joules
  - 4.18 Joules to change 1 gram of water +1 K
  - 1 calorie to change 1 gram of water +1 K
  - (note 1000 calories = 1 Calorie) so 1 peanut contains 10 Calories or 10,000 calories
  - Our bodies metabolize (burn) food to keep us warm, do useful work, or just goof off

Specific Heat Capacity

- *The quantity of heat needed to raise the temperature of one gram of a substance by 1° Celsius*
  - Measures the resistance of a substance to temp. changes
    - Thermal inertia
  - Works both ways
    - Substances that take longer to heat up also take longer to cool
  - How does the high specific heat of water affect weather in the U.S.?

Which has a higher specific heat, the filling or the crust?

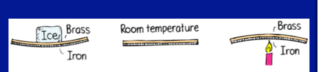
Thermal Expansion

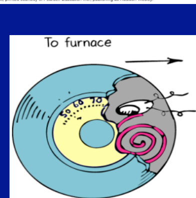
- Why do objects tend to expand when heated and contract when cooled?

Thermal Expansion

- Why do objects tend to expand when heated and contract when cooled?
  - As temperature increases, molecules jiggle faster and move farther apart
- Important engineering consideration
  - Ex. Expansion joints in bridges
    - Golden gate bridge contracts more than a meter in cold weather

DEMO - Bi-metal strip





The unequal expansion of a bimetallic strip can operate a thermostat.

Thermal Expansion

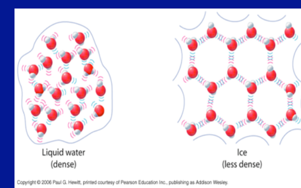
- Important engineering consideration
  - Ex. #2 Support structure for telescopes.
    - VLA dishes experience pointing offset if one side is warmed by the sun and the other side is in the shade

Why Does Ice Float?

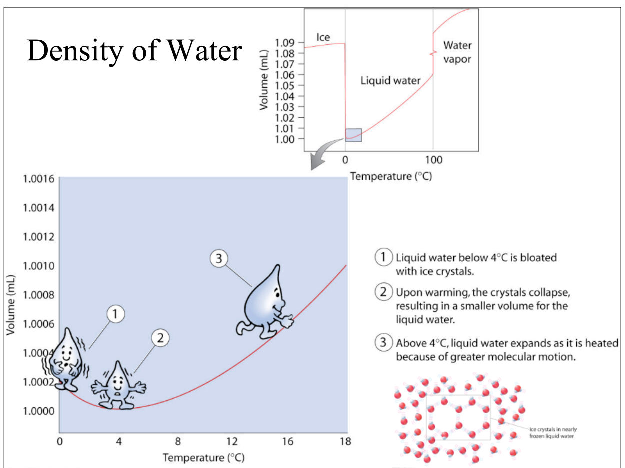
- What must be true of any substance in order for it to float in water?

Why Does Ice Float?

- Unlike most materials, H_2O expands as it freezes
  - Ice is less dense than liquid water => flotation
  - Due to crystalline structure of ice
    - Greater spacing between molecules than in the liquid phase



Density of Water



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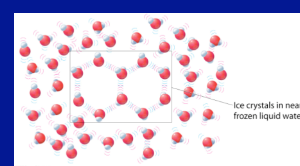
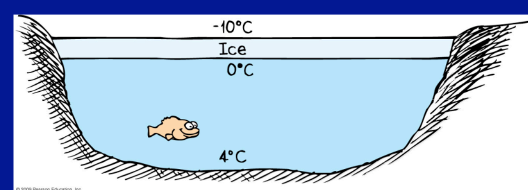




Clicker Question:

Which of the following is not a property of matter:

A: mass

B: temperature

C: heat

D: internal energy

Clicker Question:

Which of the following cannot be expressed in Joules?

A: heat

B: kinetic energy

C: temperature

D: work

Clicker Question:

How is it that people can firewalk and not get burned?

A: They consume large amounts of asbestos to develop fire-proof feet.

B: The coals are not actually very hot.

C: The coals are not efficient at heat transfer (have poor thermal conductivity).

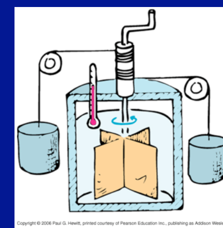
D: They run above the coals and don't actually make contact with them.

Thermodynamics

- *The study of heat and its transformation to mechanical energy and work*
  - *1st law of thermodynamics*
    - *When heat flows into (or out of) a system, the system gains (or loses) an amount of energy equal to the amount of heat transferred.*

ΔHeat = ΔInternal Energy + Work

  - *Adding heat to a system can:*
    - *increase the internal energy of the system*
    - *enable the system to do external work (or both)*



Device demonstrating the conversion of mechanical energy to heat energy

1st Law (cont.)

- What fundamental principle in physics does the 1st law express?

1st Law (cont.)

- What fundamental principle in physics does the 1st law express?
  - Conservation of energy (*ΔHeat = ΔInternal Energy + Work)*
    - Holds for all systems, regardless of the specifics of their inner workings
- Adding heat
  - to fixed volume (sealed container of air)
    - How does the temperature and pressure of the air change?
    - How much work is done? Where does the energy go?
  - to changeable volume (e.g. Piston)
    - What happens to the piston?

1st Law (cont.)

- If we do mechanical work on a system, we can also increase its internal energy
  - Your hands get warmer if you rub them together
  - What happens to the air in a bicycle pump as the handle is pushed down?

1st Law (cont.)

- If we do mechanical work on a system, we can also increase its internal energy
  - Your hands get warmer if you rub them together
  - What happens to the air in a bicycle pump as the handle is pushed down?
    - Air is compressed and temperature (measure of internal energy) rises
- You can always transform mechanical energy completely into heat, but you can never transform heat completely into mechanical energy!
  - Directionality to nature of heat flow and energy

DEMO - Fire Syringe

- Imagine two bricks at different temperatures in thermal contact
  - If the hot brick were able to extract heat from the cold brick, would this violate the 1st law of thermodynamics?

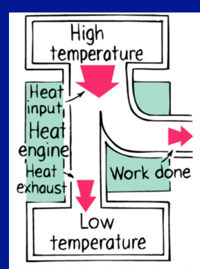
2nd Law of Thermodynamics

- Imagine two bricks at different temperatures in thermal contact
  - If the hot brick were able to extract heat from the cold brick, would this violate the 1st law of thermodynamics?
    - No. Not if the cold brick becomes even colder so that the total amount of energy is conserved.
  - This sort of behavior is prohibited by the <u>2nd law of thermodynamics:</u>
    - *Heat never spontaneously flows from a cold object to a hotter object.*
      - Heat can be made to flow in the opposite direction, but only by doing work on the system or by adding energy from another source.

Heat Engines

- Heat = disordered energy – random thermal motion
- Alternative statement of 2nd law:
  - No device is possible whose <u>sole</u> effect is to transform heat <u>completely</u> into work.
  - There is a maximum efficiency ($\eta < 1$) for <u>any</u> heat engine - 3rd law
    - Depends only on operating temps.
      - It is easy to convert work entirely into heat, e.g., friction
      - Reverse is not possible

Demo - Stirling Engine



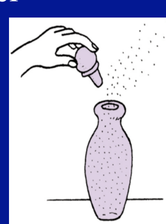
Some heat must always be "wasted" (exhausted to a low temperature reservoir)

$$\eta = \frac{T_{hot} - T_{cold}}{T_{hot}}$$

- If you open a bottle of perfume, what happens to the perfume molecules?

Entropy and Disorder

- 2nd Law – Systems left to themselves evolve towards states of increasing disorder
  - Entropy: Measure of disorder
    - Organized energy (e.g. gasoline) degenerates to disorganized and less useful energy (heat)
    - Perfume diffuses in a room – goes from organized state (all molecules in bottle) to more disordered state (all throughout room)
    - Defines an "arrow" of time
      - Some processes are time-irreversible



Will the perfume molecules scattered throughout the room ever all spontaneously return to the bottle?

Entropy and Disorder (cont.)

- Disordered energy can be changed to ordered energy only with organizational effort or work input
  - Work put into refrigeration cycle => water freezes (more ordered state)
  - Gas compressed into a smaller volume requires outside work to be done on the gas
  - Living organisms concentrate and organize energy from food sources
  - In each case, the entropy of the system decreases. Do these examples violate the 2nd law of Thermo?

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  - In each case the entropy of the system decreases. Do these examples violate the 2nd law of Thermo?
    - No. In each entropy of the environment increases, which more than compensates for the decrease in entropy. The total entropy of the universe always increases (or stays the same) in any given process.

3rd Law of Thermodynamics

- No system can reach a temperature of 0 K (absolute zero)

Lessons from Thermodynamics

1) You can't win
2) You can't break even
3) You can't get out of the game

Clicker Question:

Which of the following must always increase for any physical process (like a chemical reaction)?

A: energy

B: temperature

C: entropy

D: heat

Clicker Question:

What is the temperature at the bottom of a deep lake when their is ice on the top?

A: -4° C

B: 0° C

C: 4° C

D: 10° C

Clicker Question:

Conservation of energy is most clearly related to:

A: First law of thermodynamics

B: Second law of thermodynamics

C: Third law of thermodynamics

D: First law of entropy