Physics Unit 6

- This Slideshow was developed to accompany the textbook
  - *OpenStax Physics*
    - *Available for free at https://openstaxcollege.org/textbooks/college-physics*
  - *By OpenStax College and Rice University*
  - *2013 edition*
- Some examples and diagrams are taken from the textbook.

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06-01 Temperature and Thermal Expansion

In this lesson you will…

• Define temperature.

• Convert temperatures between the Celsius, Fahrenheit, and Kelvin scales.

• Define thermal equilibrium.

• State the zeroth law of thermodynamics.

• Define and describe thermal expansion.

• Calculate the linear expansion of an object given its initial length, change in temperature, and coefficient of linear expansion.

• Calculate the volume expansion of an object given its initial volume, change in temperature, and coefficient of volume expansion.

06-01 Temperature and Thermal Expansion

- Do the lab handout.
- Three stations, so rotate through them.

- Station 1 – Ring and Ball
- Station 2 – Bimetallic Strip
- Station 3 – Bimetallic Disc

06-01 Temperature and Thermal Expansion

- Common temp scales
  - Celsius (centigrade)
    - Water freezes at 0°C
    - Water boils at 100°C
  - Fahrenheit
    - Water freezes at 32°F
    - Water boils at 212°F
  - $T_C = \frac{5}{9}(T_F - 32)$
- Kelvin (K)
  - Notice it is NOT degrees Kelvin
  - 0 K = absolute zero (temperature cannot be less than this)
  - 273.15 K = 0°C (water freezing)
  - 373.15 K = 100°C (water boiling)
  - $T_K = T_C + 273.15$

The width of 1°C = 9/5°F

06-01 Temperature and Thermal Expansion

- Convert 30°C to °F and K

- 86°F
- 303.15 K

$$T_C = \frac{5}{9}(T_F - 32)$$
$$30 = \left(\frac{5}{9}\right)(T_F - 32)$$
$$54 = T_F - 32$$
$$86 = T_F$$

$$T_K = T_C + 273.15$$
$$T_K = 30 + 273.15$$
$$T_K = 303.15$$

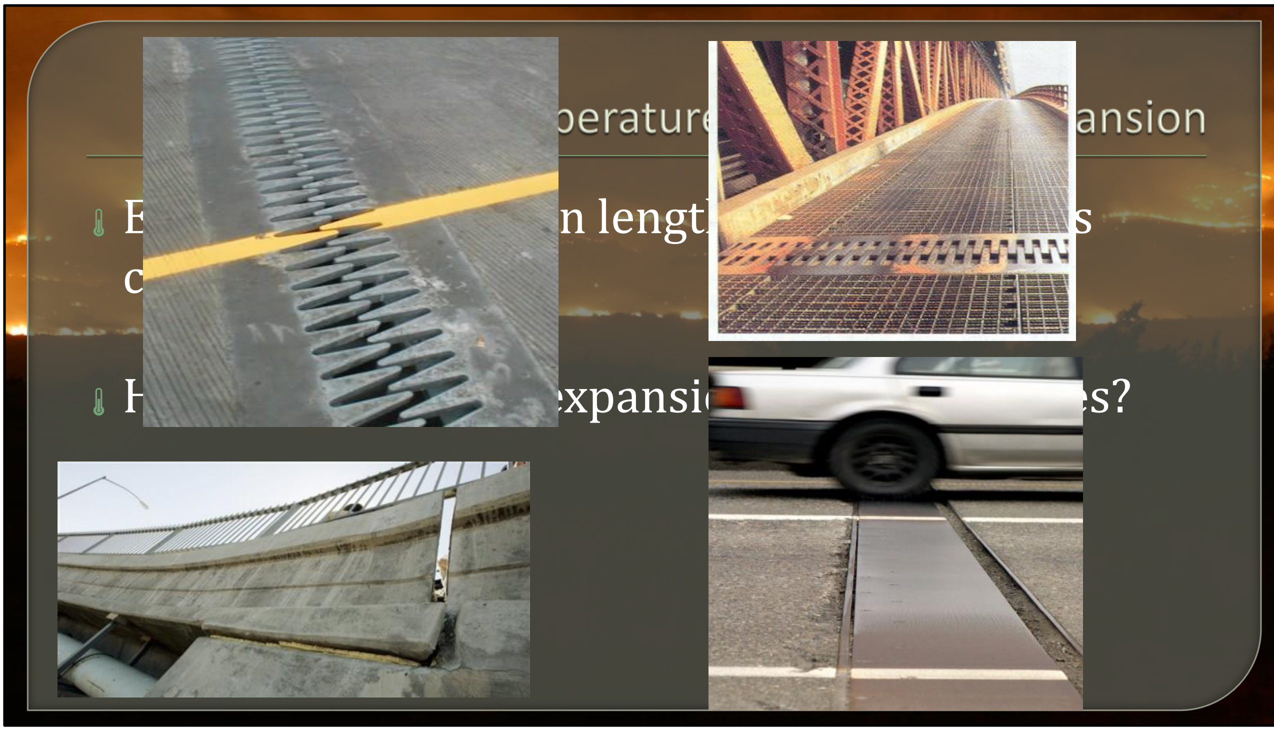
06-01 Temperature and Thermal Expansion

- Heat always flows from hotter object to colder object until thermal equilibrium
- Zeroth Law of Thermodynamics
  - If A and B are in equilibrium, and B and C are in equilibrium, then A and C are in equilibrium

06-01 Temperature and Thermal Expansion

- Normal Solids
  - How do you open a glass jar if the metal lid is too tight?
    - Run it under hot water
    - The lid expands as the temperature increases

- Linear Expansion
  - Expansion in 1-dimension as temperature changes
  - $\Delta L = \alpha L \Delta T$

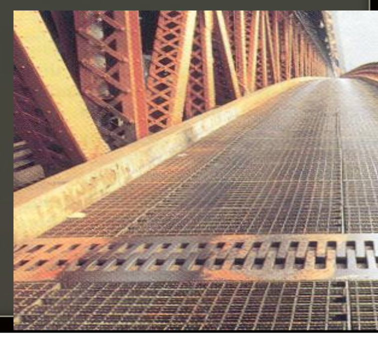


If the space is not provided for expansion, then the road/bridge would buckle

06-01 Temperature and Thermal Expansion

- A steel bridge is 2 km long. If the temperature when it was built was 21°C (70°F), what length expansion joints are needed to prevent buckling at 43°C (110°F)?

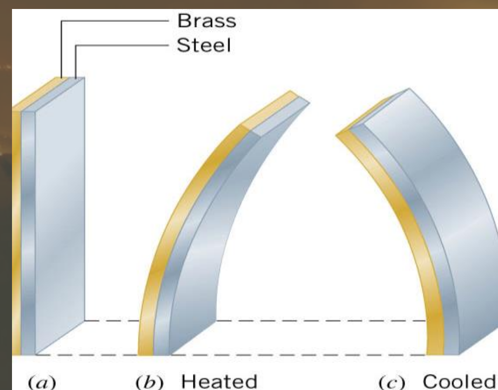
- $\Delta L = 0.528$ m



$$\Delta L = \alpha L \Delta T$$
$$\Delta L = (12 \times 10^{-6}\,°C^{-1})(2000\,m)(43\,°C - 21\,°C) = 0.528\,m$$

06-01 Temperature and Thermal Expansion

- Bimetallic Strip
  - Made from two strips of metal that have different coefficients of linear expansion
  - One side expands more than the other causing the strip to bend
  - Used in automatic switches in appliances and thermostats



Coffee maker described on p344

06-01 Temperature and Thermal Expansion

- Area thermal expansion
  - $\Delta A = 2\alpha A \Delta T$
- Volume thermal expansion
  - $\Delta V = \beta V \Delta T$
  - β = coefficient of volume expansion
    - Usually is about 3α

06-01 Temperature and Thermal Expansion

- Why do fluids in the car usually have a reservoir tank (radiator, brake fluid, power steering fluid, oil)?

- As the fluids heat, the volume increases
- There needs to be some place for the extra fluid to go

06-01 Temperature and Thermal Expansion

- Water
  - Water is unique
  - The volume of water decreases from 0°C to 4°C
  - Then water expands from 4°C and up
  - Water is the densest (least expanded) at 4°C
  - As the weather gets cold, the lake water cools and sinks because it becomes more dense pushing the warmer water up
  - After all the water is 4°C, the top starts to freeze
  - Because the 0°C water is less dense than the 4°C water, it floats
  - The ice floats and provides insulation for the warmer water underneath so it does not freeze

06-01 Homework

- Expand your mind with these questions
- Read 13.3, 13.4

06-02 Ideal Gas Law and Kinetic Theory

In this lesson you will…

- State the ideal gas law in terms of molecules and in terms of moles.
- Use the ideal gas law to calculate pressure change, temperature change, volume change, or the number of molecules or moles in a given volume.
- Use Avogadro's number to convert between number of molecules and number of moles.
- Express the ideal gas law in terms of molecular mass and velocity.
- Define thermal energy.
- Calculate the kinetic energy of a gas molecule, given its temperature.
- Describe the relationship between the temperature of a gas and the kinetic energy of atoms and molecules.

06-02 Ideal Gas Law and Kinetic Theory

- Do the lab handout.
- Three stations, so rotate through them.
- Station 1 – Marshmallow Syringe
- Station 2 – Fire Syringe
- Station 3 – Soda Can

06-02 Ideal Gas Law and Kinetic Theory

- Coefficient of expansion β is almost the same for most gases
- At low densities, gas molecules are far apart so they don't interact much

- Ideal Gas Law
  - $PV = NkT$
- Where
  - P = pressure (Pa)
  - V = volume (m^3)
  - N = number of particles (unitless)
  - k = Boltzmann's constant = $1.38 \times 10^{-23}\ J/K$
  - T = temperature (K)

06-02 Ideal Gas Law and Kinetic Theory

- Large number of molecules in a sample
- Convenient to have a unit for a large number of things
- Mole (mol)
  - Actually gram-mole
  - Number of atoms of C^{12} in 12 grams
  - Number of atoms per mole = 6.022×10^{23}
  - Avogadro's number $N_A = 6.022 \times 10^{23}\ mol^{-1}$

06-02 Ideal Gas Law and Kinetic Theory

- Number of moles in a sample

$$n = \frac{N}{N_A}$$

- Where
  - n = number of moles
  - N = number of particles
  - $N_A = 6.022 \times 10^{23}\ mol^{-1}$

06-02 Ideal Gas Law and Kinetic Theory

- Number of moles can be found from mass

$$n = \frac{m}{molar\ mass}$$

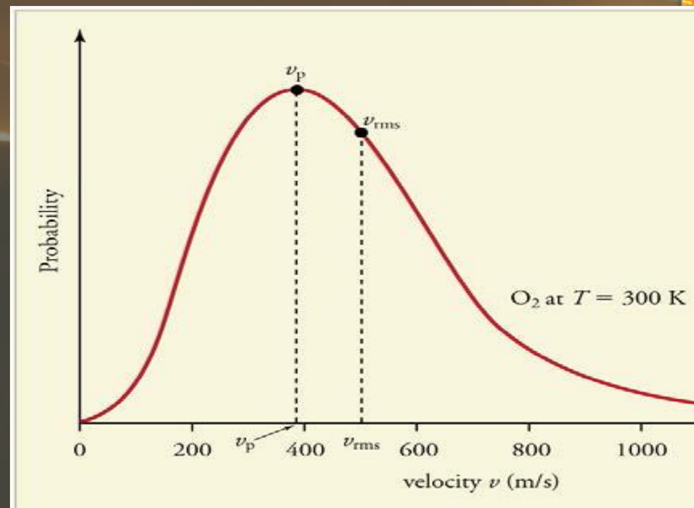
- Where
  - n = number of moles
  - m = mass of sample
  - Molar mass = same number as atomic mass from periodic table (g/mol)

06-02 Ideal Gas Law and Kinetic Theory

- Ideal Gas Law (moles)
$$PV = nRT$$
- Where
  - P = pressure (Pa)
  - V = volume (m^3)
  - n = number of moles (mol)
  - R = universal gas constant (8.31 J/(mol K)) = $N_A k$
  - T = temperature (K)
- PV is energy
  - $P = \frac{F}{A}$
  - $V = A \cdot d$
  - $PV = \frac{F}{A} A \cdot d = Fd = energy$
- nRT or NkT is energy too
  - N and k are just numbers, so T must be energy
  - T is average KE of molecules

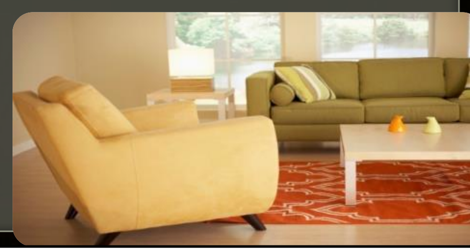
06-02 Ideal Gas Law and Kinetic Theory

- $PV = NkT = \frac{1}{3}Nm\overline{v}^2$
- $\overline{KE} = \frac{1}{2}m\overline{v}^2 = \frac{3}{2}kT$
  - $v_{rms} = \sqrt{\frac{3kT}{m}}$
  - Not all the molecules go the same speed
  - Higher T, means higher v_{rms}



06-02 Ideal Gas Law and Kinetic Theory

- An apartment has a living room whose dimensions are 2.5 m × 4.0 m × 5.0 m. Assume that the air in the room is composed of 79% nitrogen (N_2) and 21% (O_2). At a temperature of 22 °C and a pressure of 1.01×10^5 Pa, what is the mass of the air?
- m = 59430 g
  - 59.4 kg = 131 lbs



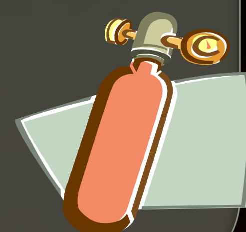
$$P = 1.01 \times 10^5\ Pa$$
$$V = 2.5\ m \times 4.0\ m \times 5.0\ m = 50\ m^3$$
$$n = ?$$
$$R = 8.31\ J/mol\ K$$
$$T = 22\ °C = 295\ K$$

$$(1.01 \times 10^5\ Pa)(50\ m^3) = n\left(8.31\frac{J}{mol\ K}\right)(295\ K) \rightarrow n = 2060\ mol$$

$$n = \frac{m}{molar\ mass}$$
$$2060\ mol = \frac{m}{\left(0.79 \cdot 2 \cdot 14.0067\frac{g}{mol} + 0.21 \cdot 2 \cdot 15.9994\frac{g}{mol}\right)}$$
$$m = 59430\ g$$

06-02 Ideal Gas Law and Kinetic Theory

- Helium, a monatomic gas, fills a 0.010-m^3 container. The pressure of the gas is 6.2 × 10^5 Pa.
  - If there are 3 mol of gas, what is the temperature of the gas?
    - T = 249 K
  - What is the v_{rms}?
    - v_{rms} = 1240 m/s



$$PV = nRT$$

$$(6.2 \times 10^5\ Pa)(0.010\ m^3) = (3\ mol)\left(8.31\frac{J}{mol}\right)T$$

$$T = 248.7\ K$$

$$n = \frac{m}{molar\ mass} = \frac{N}{N_A} \rightarrow m = \frac{1 \cdot \left(4.0026\frac{g}{mol}\right)}{6.022 \times 10^{23}\frac{}{mol}} = 6.65 \times 10^{-24}\ g$$

$$= 6.65 \times 10^{-27}\ kg$$

$$v_{rms} = \sqrt{\frac{3kT}{m}} = v_{rms} = \sqrt{\frac{3\left(1.38 \times 10^{-23}\frac{J}{K}\right)(248.7\ K)}{6.65 \times 10^{-27}\ kg}} = 1244\ m/s$$

06-02 Homework

- Ideally you should be able to answer these questions
- Read 13.5, 13.6

06-03 Phase Changes and Humidity

In this lesson you will…

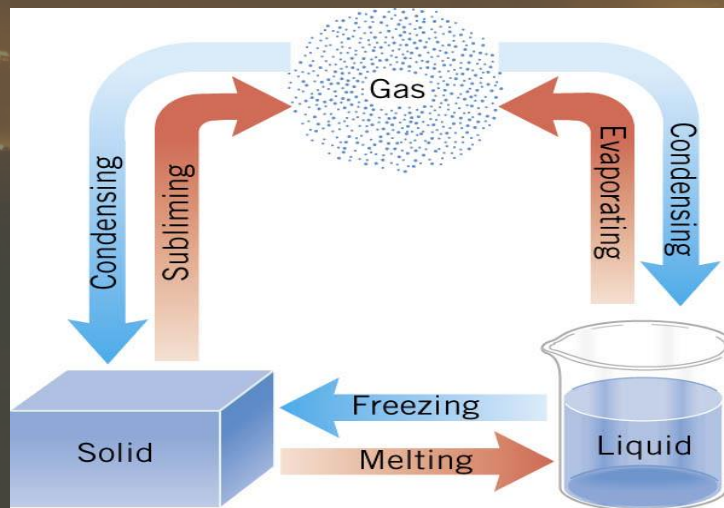
- Interpret a phase diagram.
- Identify and describe the triple point of a gas from its phase diagram.
- Describe the state of equilibrium between a liquid and a gas, a liquid and a solid, and a gas and a solid.
- Explain the relationship between vapor pressure of water and the capacity of air to hold water vapor.
- Explain the relationship between relative humidity and partial pressure of water vapor in the air.
- Calculate vapor density using vapor pressure.
- Calculate humidity and dew point.

06-03 Phase Changes and Humidity

- Do the lab handout
- Fill the flask about 1/3 full of water.
- Put the flask on the heat source and bring the water to a boil.
- After the water has been boiling enough to fill the top of the flask with steam, put the stopper on the flask (it will not stay because the steam is escaping).
- Remove the flask from the heat (with the stopper still on).
- When the water quits boiling, put the flask in the cool water. Watch the water in the flask.
- What happens to the water in the flask?
- How could that happen when the water is cooler?

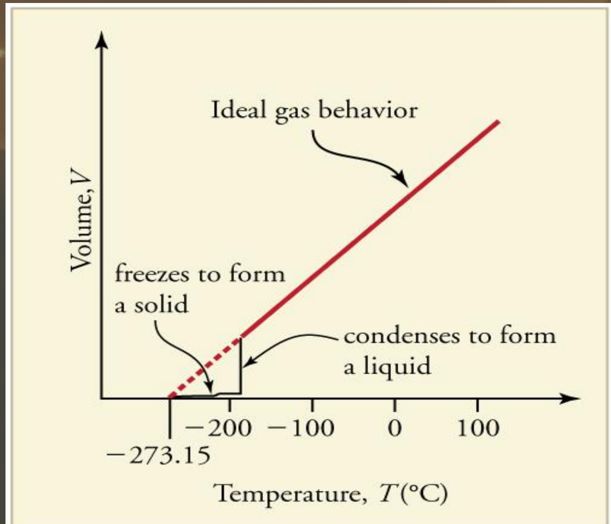
06-03 Phase Changes and Humidity

- Phase Changes



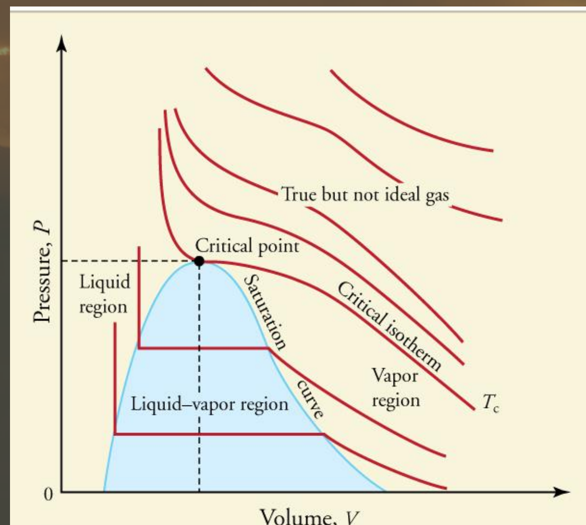
06-03 Phase Changes and Humidity

- Constant Pressure
  - High temps gases have ideal behavior
  - Colder, volume drops and forms liquid
  - Colder yet, volume drops and forms solid



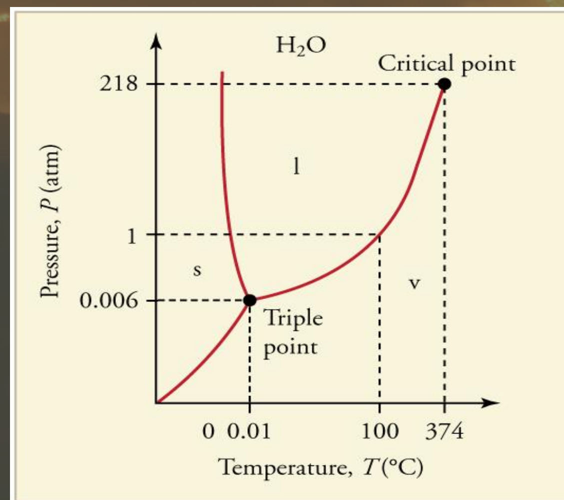
06-03 Phase Changes and Humidity

- Constant Temperature (PV diagram)
  - Critical Point
    - Temperature above which liquid cannot exist
    - Minimum pressure needed for liquid



06-03 Phase Changes and Humidity

- Constant Volume (phase diagram)
  - Critical point
    - Above this temp, no liquid
  - Triple point
    - All 3 phases coexist
  - Lines
    - 2 phases coexist



06-03 Phase Changes and Humidity

- Vapor Pressure
  - The pressure at which a gas coexists with its solid or liquid phase.
  - Faster molecules break away from liquid or solid to form vapor
- Partial Pressure
  - The pressure a gas would create if there were no other gases present.
- Total pressure
  - Total of all partial pressures of all gases present

06-03 Phase Changes and Humidity

- Relative Humidity
  - How much water vapor is in air
  - At 100% humidity, partial pressure of water = vapor pressure
  - If partial pressure < vapor pressure → evaporation
  - If partial pressure > vapor pressure → condensation
- Hotter means higher partial pressure of water
  - Hot air can hold more water
- Saturation Vapor Density
  - Maximum amount of water vapor that air can hold at various temp
- Percent Humidity
  - $\%\ Relative\ Humidity = \frac{vapor\ density}{saturation\ vapor\ density} \times 100\%$

PV=nRT

As air cools, partial pressure of water decreases. At dew point, partial pressure=vapor pressure and water vapor starts to condense

06-03 Phase Changes and Humidity

- What pressure is necessary to raise the boiling point of water to 150 °C? If this was a sealed container, what would the gauge pressure be?

- Pressure = 4.76×10^5 Pa
- Gauge pressure = 3.75×10^5 Pa

Pressure: from table 13.5 vapor pressure at 150 °C = 4.76×10^5 Pa

Gauge pressure: $Gauge\ pressure = total\ pressure - air\ pressure$

$$gauge\ pressure = 4.76 \times 10^5\ Pa - 1.01 \times 10^5\ Pa = 3.75 \times 10^5\ Pa$$

06-03 Phase Changes and Humidity

- Late on an autumn day, the relative humidity is 45.0% and the temperature is 20.0 °C. What will the relative humidity be that evening when the temperature has dropped to 10.0 °C, assuming constant water vapor density?

- 82.3 %

$$\%\ humidity = \frac{\text{vapor pressure}}{\text{saturation vapor pressure}} \times 100\%$$

From table 13.5, saturation vapor pressure at $20.0\ °C = 17.2\ g/m^3$

$$45\% = \frac{VP}{17.2\,\frac{g}{m^3}} \times 100\%$$

$$7.74\,\frac{g}{m^3} = VP$$

From table 13.5, saturation vapor pressure at $10.0\ °C = 9.40\ g/m^3$

$$\%\ humidity = \frac{7.74\,\frac{g}{m^3}}{9.40\,\frac{g}{m^3}} \times 100\%$$

$$\%\ humiodity = 82.3\ \%$$

06-03 Homework

- I hope these problems won't make you boiling mad.
- Read 14.1, 14.2

06-04 Heat and Temperature Change

In this lesson you will…

- Define heat as transfer of energy.
- Observe heat transfer and change in temperature and mass.
- Calculate final temperature after heat transfer between two objects.

06-04 Heat and Temperature Change

- Heat is energy that flows from a higher-temperature object to a lower-temperature object because of the difference in temperatures
- Unit: Joule (J), calorie (cal), kilocalorie (kcal or Cal)
- If an object feels hot, the heat is flowing into you
- If an object feels cold, the heat is flowing out of you
- Mechanical Equivalent of Heat
  - Since heat is energy, other types of energy can make the same effect as heat
    - 1.000 kcal = 4186 J

Results when internal energy from kinetic energy of molecules is transferred

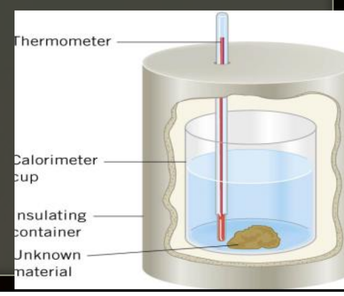
Calorie = raise 1 g of water 1 °C
Kilocalorie = 1000 calories = raise 1 kg of water 1 °C

06-04 Heat and Temperature Change

- To increase the temperature of an object heat is required
  - The amount of heat required is related to
    - Mass of the object
    - Amount of temperature change
    - Material of the object
- $Q = mc\Delta T$
  - Q = heat
  - c = specific heat capacity (based on material Table 14.1)
  - m = mass
  - ΔT = change in temperature

06-04 Heat and Temperature Change

- Measuring the change in temperature of different heated objects (usually water and an unknown) inside a thermos can be used to measure the specific heat capacity of the object
- This can be used to identify the unknown material



06-04 Heat and Temperature Change

- A pot of 10 kg of 15-°C water is put on a stove and brought to a boil. How much heat was needed?
- Q = $3.56 \times 10^6\ J$

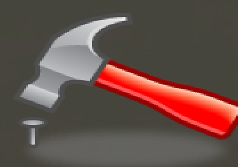
$$Q = mc\Delta T$$

$$Q = \left(4186 \frac{J}{kg\ °C}\right)(10\ kg)(100°C - 15°C)$$

$$Q = 3558100\ J$$

06-04 Heat and Temperature Change

- What is the increase in temperature of a 50 g nail hit by a hammer with force of 500N? The length of the nail is .06m its specific heat capacity is 450 J/kg°C.
- $\Delta T = 1.33\ °C$



$$Q = mc\Delta T$$

$$Q = energy = work = Fs = (500\ N)(0.06\ m) = 30\ J$$

$$30\ J = (0.050\ kg)\left(450\frac{J}{kg°C}\right)\Delta T$$

$$\Delta T = 1.33\ °C$$

06-04 Heat and Temperature Change

- Do the lab handout.
- A hot marble will be placed into cool water. The heat will transfer from the marble into the water until they are the same temperature. The amount of heat that leaves the marble is the same as the heat absorbed by the water. By knowing the change in temperature and amount of water, we can calculate the specific heat capacity of the marble.
- Where could errors have come from?

Heat escaping to the environment.

06-04 Homework

- How much does the temperature of your pencil rise as you do these problems?
- Read 14.3

06-05 Phase Change and Latent Heat

In this lesson you will…
- Examine heat transfer.
- Calculate final temperature from heat transfer.

06-05 Phase Change and Latent Heat

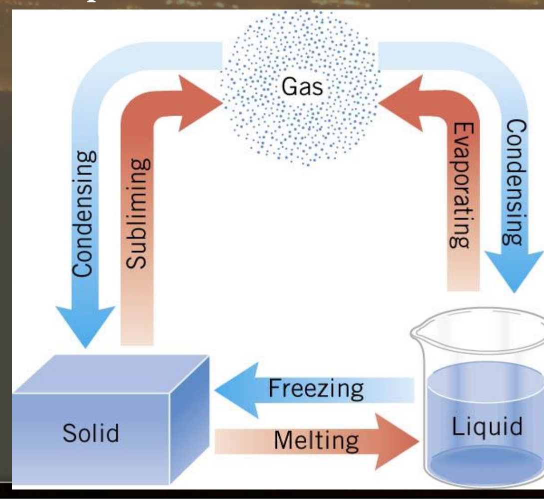
- Start the lab handout.
- Measurements will be taken every few minutes, but we will start the lesson, then pause for the measurements.
- Boiling water – Mr. Wright has the water.
- Ice Water – Students have the ice water.

06-05 Phase Change and Latent Heat

- Energy is required to (or released by) changing the molecular bonds in states of matter
- It takes energy to break the crystal structure to change from solid to liquid

06-05 Phase Change and Latent Heat

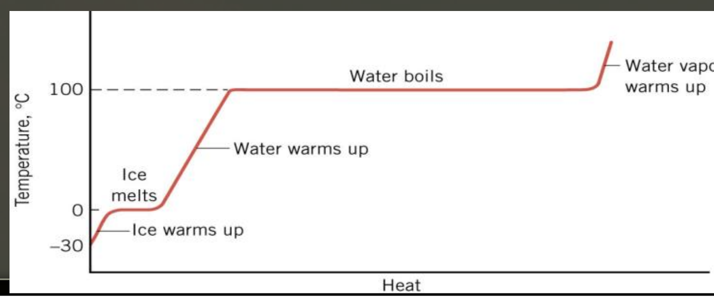
- Heat does not always change the temperature of a material
- Phases of matter
  - Solid
  - Liquid
  - Gas
- Blue arrows release energy
- Red arrows absorb energy



Be sure to define the term for each change of phase

06-05 Phase Change and Latent Heat

- Typical process (water)
  - Ice warms up (temperature change)
  - Ice melts (no temperature change until no ice)
  - Water warms up (temperature change)
  - Water boils (no temperature change until no liquid)
  - Steam warms up



06-05 Phase Change and Latent Heat

- When you cook pasta (or anything that requires boiling), is it better to have a vigorous boil or to turn down the heat to produce barely boiling water?

- As long as the water is boiling, it is at 100°C
- It is saves energy if you use barely boiling water

06-05 Phase Change and Latent Heat

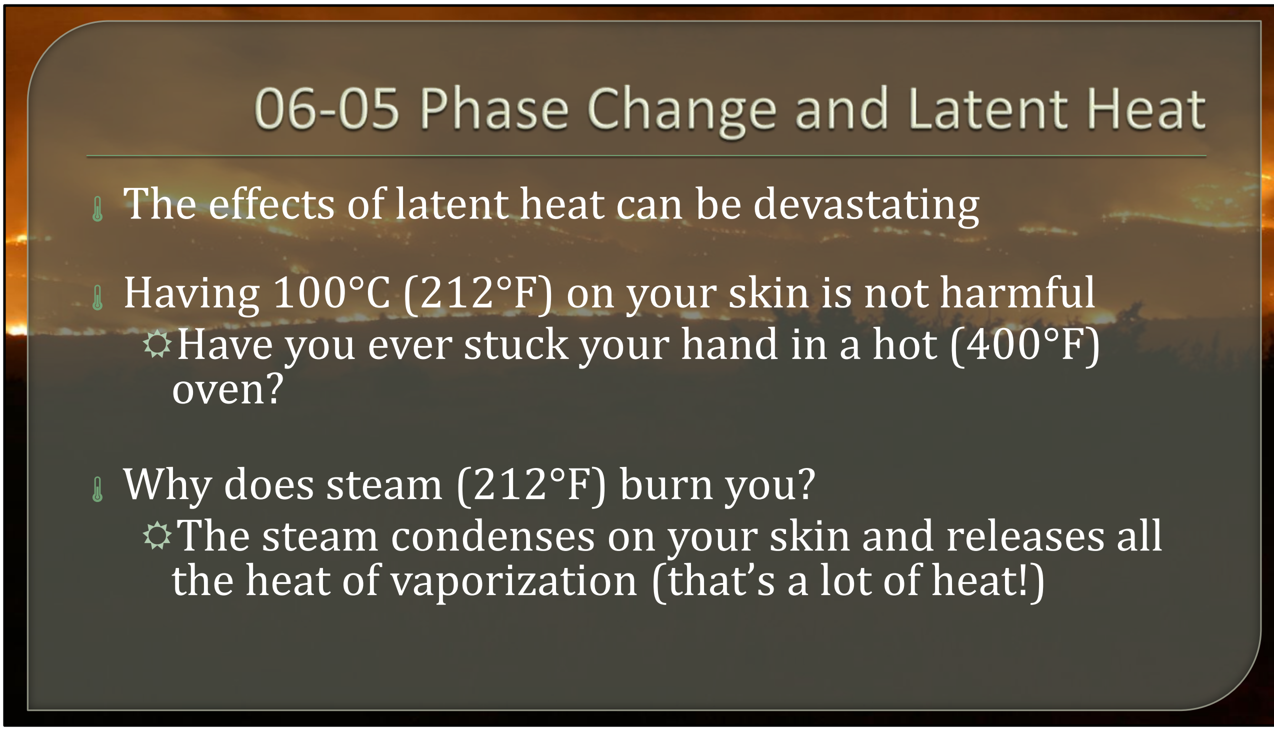
- Latent heat
  - The amount of heat per kilogram required to change phase

- $Q = mL$

- Q = heat required
- m = mass
- L = latent heat

06-05 Phase Change and Latent Heat

- Latent heat of fusion (L_f)
  - Refers to change between solid and liquid
- Latent heat of vaporization (L_v)
  - Refers to change between liquid and gas
- Latent heat of sublimation (L_s)
  - Refers to change between solid and gas
- See table 14.2



One winter, I was near the wood stove and bumped it with a my hand in a wet glove. The water in the glove vaporized, then that hot vapor condensed on my skin causing burns.

06-05 Phase Change and Latent Heat

- You have a glass of 1-kg warm water (25°C). To make it cold you put in some ice cubes (-5°C). After an equilibrium temperature is reached, there is a little ice left. What is the minimum mass of the ice cubes? (Assume no heat is lost to the environment.)

- m = 0.303 kg

$$\text{Water cools}$$
$$C = 4186\ J/(kg°C)$$
$$m = 1\ kg$$
$$\Delta T = T_f - T_0 = 0\ °C - 25\ °C = -25\ °C$$
$$Q = Cm\Delta T = \left(4186 \frac{J}{kg}°C\right)(1\ kg)(-25\ °C) = -104650\ J$$

$$\text{Ice warms}$$
$$C = 2000\ \ J/kg°C$$
$$m = m$$
$$\Delta T = 0\ °C - \ -5\ °C = 5\ °C$$
$$Q = \left(2000 \frac{J}{kg°C}\right)(m)(5\ °C) = \left(10000 \frac{J}{kg}\right)m$$

$$\text{Ice melts}$$
$$L_f = 335000 \frac{J}{kg}$$
$$Q = m\left(335000 \frac{J}{kg}\right)$$

$$Q + Q + Q = 0$$
$$-104650\ J + \left(10000 \frac{J}{kg}\right)m + \left(335000 \frac{J}{kg}\right)m = 0$$
$$\left(345000 \frac{J}{kg}\right)m = 104650\ J$$
$$m = 0.303\ kg$$

06-05 Homework

- Don’t let these problems phase you
- Read 14.4, 14.5

06-06 Conduction

In this lesson you will…

- Discuss the different methods of heat transfer.
- Calculate thermal conductivity.
- Study thermal conductivities of common substances.

06-06 Conduction

- Do the lab handout.

- Put a small pat of butter on the curved end of each spoon.
- Stick a bead to each pat of butter.
- Set the spoons in the beaker with the butter side up. The handles will be downward.
- Boiling water will be poured in the beaker. Predict the order that the butter will melt.

06-06 Conduction

- Conduction
  - Process where heat is transferred through a material without any movement of the material
  - The objects are in contact with each other
- Often happens when energetic hot molecules bump into less energetic cool molecules
  - When this happens energy is transferred

Remember the molecules of all materials are constantly moving. More motion means more energy and a higher temperature.

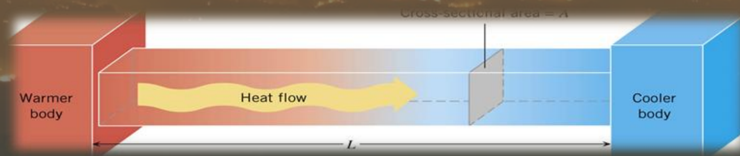
06-06 Conduction

- Thermal conductors
  - Materials that conduct heat well
  - Metals
- Thermal insulators
  - Materials that conduct heat poorly
  - Wood, plastic, glass

06-06 Conduction

- Conduction of Heat Through a Bar

$$\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$$



  - k = thermal conductivity (Table 14.3)
  - A = cross-sectional area
  - $T_2 - T_1$ = difference in temperature between ends
  - t = time of heat transfer
  - d = length of bar

06-06 Conduction

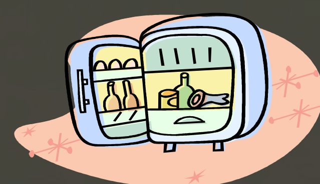
- There are two ways to create good insulators
  - Small k and big d
  - Ratio d/k called R factor
    - Higher the R factor, better insulator

- Other insulators like goose down and Styrofoam work by trapping air in small spaces where convection currents cannot arise

06-06 Conduction

- How much heat is transferred through the Styrofoam insulation the walls of a refrigerator in an hour? The total area of the walls are about 4 m^2 and the Styrofoam is 30mm thick. The temperature inside is 5°C and the room is 25°C.

- Q = 96000 J



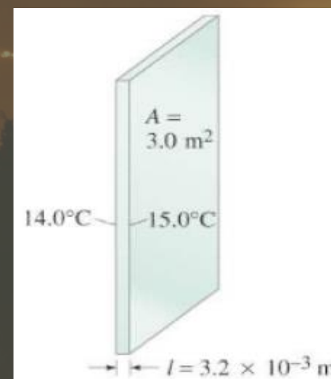
$$\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$$

$$\frac{Q}{3600\ s} = \frac{\left(0.01\,\frac{J}{sm°C}\right)(4\ m^2)(25\ °C - 5\ °C)}{0.03\ m}$$

$$Q = 96000\ J$$

06-06 Conduction

- A major source of heat loss from a house is through the windows. Calculate the rate of heat flow through a glass window 2.0 m × 1.5 m in area and 3.2 mm thick, if the temperatures at the inner and outer surfaces are 15.0°C and 14.0°C, respectively.



- 790 J/s

$$\frac{Q}{t} = \frac{kA(T_2 - T_1)}{d}$$

$$\frac{Q}{t} = \frac{\left(0.84\,\frac{J}{sm°C}\right)(2.0\ m \times 1.5\ m)(15.0\ °C - 14.0\ °C)}{3.2 \times 10^{-3}\ m} = 790\ J/s$$

06-06 Homework

- Remember to conduct yourselves as Christ-like.
- Read 14.6, 14.7

06-07 Convection and Radiation

In this lesson you will…

- Discuss the method of heat transfer by convection.
- Discuss heat transfer by radiation.

06-07 Convection and Radiation

- Start the lab handout. Measurements will be taken throughout class.
- Heat lamps emit infrared and visible light radiation which you feel as heat. You will observe the temperature of water in three different colored bottles in front of a heat lamp.
- Predict which bottle will absorb the most heat and which will absorb the least heat.

06-07 Convection and Radiation

- Convection
  - Flow of heat due to the movement of matter
  - Artificial
    - Circulatory system pumps blood
    - Radiator pumps antifreeze
  - Natural
    - Difference in densities of fluids with different temperatures
    - Warm air rises, cold air falls

06-07 Convection and Radiation

- When you are working out, your sweat evaporates to cool you. How much sweat must evaporate to lower the body temperature of a 80-kg man by 1°C?

- $m_{sweat} = 0.115\ kg$

Cooling the man: $Q = m_{man} c \Delta T$
Evaporating the sweat: $Q = m_{sweat} L_{v(37°C)}$
No net heat loss

$$m_{man} c \Delta T = m_{sweat} L_{v(37°C)}$$
$$L_{v(37°C)} = 2430 \frac{kJ}{kg} = 2.43 \times 10^6 \frac{J}{kg}$$
$$(80\ kg)\left(3500 \frac{J}{kg \cdot °C}\right)(1\ °C) = m_{sweat}\left(2.43 \times 10^6 \frac{J}{kg}\right)$$
$$m_{sweat} = 0.115\ kg$$

06-07 Convection and Radiation

- One winter day, the climate control system of a large university classroom building malfunctions. As a result, 250 m^3 of excess cold air is brought in each minute. At what rate in kilowatts must heat transfer occur to warm this air by 10.0°C (that is, to bring the air to room temperature)?
- 38.8 kW

$$P = \frac{Q}{t} = \frac{mc\Delta T}{t}$$

$$m = \rho V$$

$$m = \left(1.29 \frac{kg}{m^3}\right)(250\, m^3) = 322.5\, kg$$

$$P = \frac{(322.5\, kg)\left(721 \frac{J}{kg \cdot °C}\right)(10.0\, °C)}{60.0\, s} = 3.88 \times 10^4\, W = 38.8\, kW$$

06-07 Convection and Radiation

- Wind chill
  - Air feels colder when wind is blowing because heat is removed by convection as well as conduction.
  - See table 14.4
- At what temperature does still air cause the same chill factor as 2°C air moving at 5 m/s?

From table: -7°C

06-07 Convection and Radiation

- Heat from the sun reaches earth without contact (conduction) or movement of a fluid (convection)
- The energy is transferred by electromagnetic waves

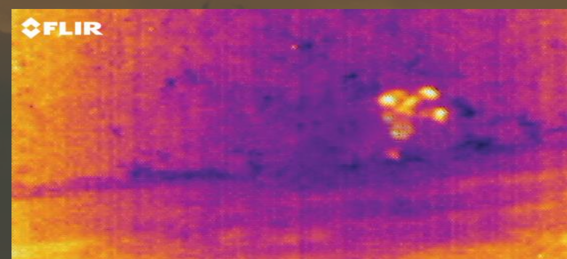
06-07 Convection and Radiation

- Radiation
  - Transfer of energy via electromagnetic waves
  - Electromagnetic waves include radio waves, microwaves, x-rays, infrared, and visible light

06-07 Convection and Radiation

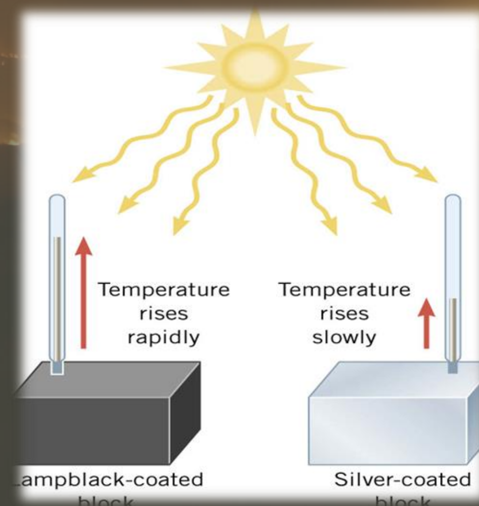
- All bodies (objects) continually emit radiation
  - Bodies like ice cubes emit very little radiation
  - Warm bodies, like human bodies, emit infrared radiation
  - When the temperature of a body reaches 1000K, it starts to emit visible dull red light
  - When the temperature of a body reaches 1700K, it emits white-hot light

06-07 Convection and Radiation



06-07 Convection and Radiation

- Different objects react differently to radiation
- Black box absorbs most of radiation
- Silver box absorbs little radiation
- The rest of the radiation is reflected



06-07 Convection and Radiation

- Black is usually a good absorber of radiation
- Blackbody is an object that absorbs all radiation that hits it
- All objects emit and absorb radiation continually
  - Good absorbers are also good emitters

06-07 Convection and Radiation

- On a sunny summer day, wear light colored clothes
- Black clothes absorb the sun's radiation
  - Then it re-emits the energy
  - Half of the re-emitted energy is on the inside of the shirt into you
- Light colored clothes absorb, and re-emit, much less radiation

06-07 Convection and Radiation

- Stefan-Boltzmann Law of Radiation

$$\frac{Q}{t} = \sigma e A T^4$$

- $\frac{Q}{t}$ = rate of heat transfer
- σ = 5.67x10^{-8} J/(s m^2 K^4)
- e = emissivity (% of radiation emitted as compared to a perfect emitter)
- A = surface area
- T = temperature in Kelvin

- Because heat is both emitted and absorbed at the same time, the net rate of heat transfer by radiation is

$$\frac{Q}{t} = \sigma e A (T_2^4 - T_1^4)$$

- T_1 = temperature of object
- T_2 = temperature of surrounding
- e = emissivity of object
- A = surface are of object

e depends on material
σ is the Stefan-Boltzmann constant

06-07 Convection and Radiation

- Find the rate that heat is radiated by the sun if the surface temperature is 6000K and emissivity = 1.

- $\frac{Q}{t} = 4.13 \times 10^{26}\ W$

$$\frac{Q}{t} = \sigma e A T^4$$

$$r_{sun} = 6.69 \times 10^8\ m, \mathrm{A} = 4\pi(6.69 \times 10^8\ m)^2 = 5.6242 \times 10^{18}\ m^2$$

$$\frac{Q}{t} = \left(5.67 \times 10^{-8} \frac{J}{sm^2K^4}\right)(1)(5.6242 \times 10^{18}\ m^2)(6000\ K)^4 = 4.13 \times 10^{26}\ J/s$$

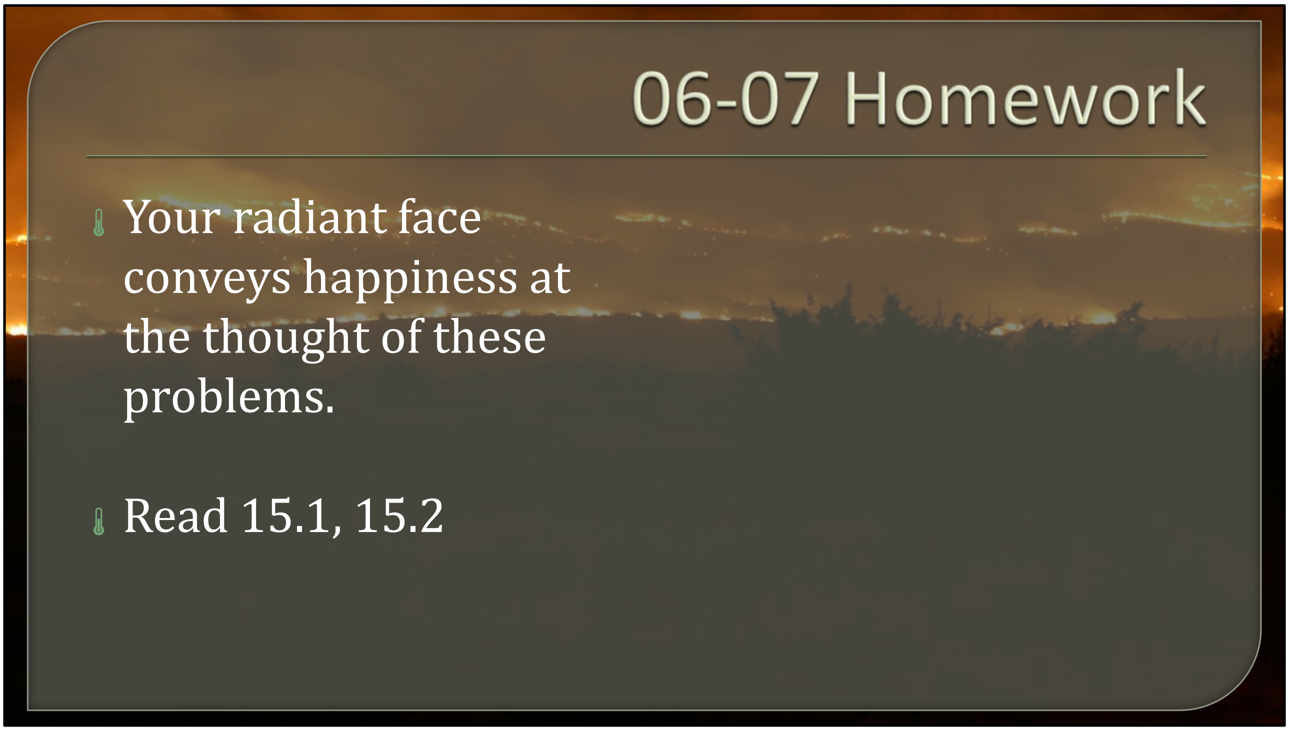
06-07 Convection and Radiation

- Find rate that heat is radiated from a bald head if we estimate that it is a sphere with radius 120 mm and emissivity of 0.97. (Body temperature is 37.0°C and the surrounding room is at 20°C)
- $\frac{Q}{t} = -18.6\ W$

$$\frac{Q}{t} = \sigma e A(T_2^4 - T_1^4)$$

$$\frac{Q}{t} = \left(5.67 \times 10^{-8}\frac{J}{sm^2K^4}\right)(0.97)(4\pi(0.12\ m)^2)\left((293.15\ K)^4 - (310.15\ K)^4\right)$$

$$\frac{Q}{t} = -18.6\frac{J}{s}$$


06-07 Homework
Your radiant face conveys happiness at the thought of these problems.
Read 15.1, 15.2

06-08 The 1st Law of Thermodynamics and Simple Processes

In this lesson you will…

- Define the first law of thermodynamics.
- Describe how conservation of energy relates to the first law of thermodynamics.
- Calculate changes in the internal energy of a system, after accounting for heat transfer and work done.
- Describe the processes of a simple heat engine.
- Explain the differences among the simple thermodynamic processes—isobaric, isochoric, isothermal, and adiabatic.
- Calculate total work done in a cyclical thermodynamic process.

06-08 The 1st Law of Thermodynamics and Simple Processes

- Thermodynamics is study of laws of heat transfer and its relationship to work

06-08 The 1st Law of Thermodynamics and Simple Processes

- Systems have internal energy due to the KE and PE of the particles in it
- Heat can be gained by the system
  - Because of conservation of energy this changes the internal energy of the system
  - Heat is positive when system gains heat
  - Heat is negative when system loses heat

06-08 The 1st Law of Thermodynamics and Simple Processes

- Work can also change internal energy of a system
  - Work is positive when it is done by the system
  - Work is negative when it done on the system

- Remember the internal energy of the system only depends on the state of the system; not how it got that way

06-08 The 1st Law of Thermodynamics and Simple Processes

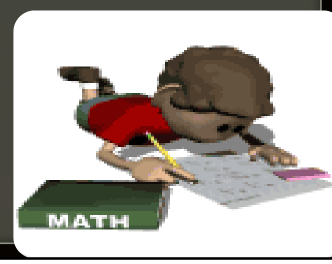
- 1st Law of Thermodynamics
  - $\Delta U = Q - W$

  - Where
    - U = internal energy = $\frac{3}{2}NkT$ for ideal gas
    - Q = heat (positive when system gains Q)
    - W = work (positive when system does W)

06-08 The 1st Law of Thermodynamics and Simple Processes

- While working on an assignment, Frank does 10000 J of work. In the process, his internal energy decreases by 20000 J. Find W, ΔU, and Q.

- W = 10000 J
- ΔU = -20000 J
- Q = -10000 J



W is positive since it is work done by the system
ΔU is negative since the internal energy decreases

$$\Delta U = Q - W$$
$$-20000\,J = Q - 10000\,J$$
$$Q = -10000\,J$$

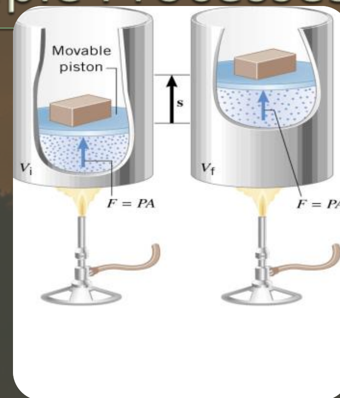
System loses lots of heat.

06-08 The 1st Law of Thermodynamics and Simple Processes

- Four thermal processes
  - Each is quasi-static → slow enough that uniform temperature and pressure

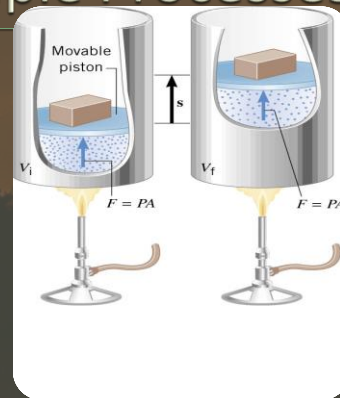
06-08 The 1st Law of Thermodynamics and Simple Processes

- Isobaric
  - Constant pressure
  - Frictionless piston where the pressure is determined by the weight of the piston (doesn't change)
  - As the gas is heated, it expands and pushes the piston up
  - W = Fs



"Iso" means same
"Bar" means pressure "barometer"

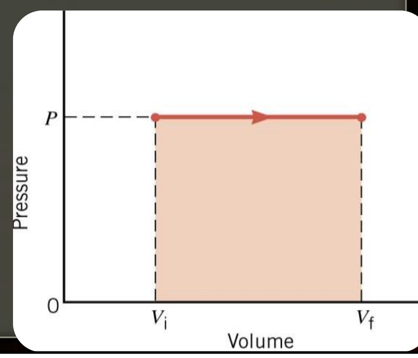
06-08 The 1st Law of Thermodynamics and Simple Processes



- Isobaric
  - $W = Fs$
  - $F = PA$
  - $W = (PA)s$
  - $As = \Delta V = V_f - V_i$
  - $W = P\,\Delta V = P(V_f - V_i)$
  - This is valid for all states of matter

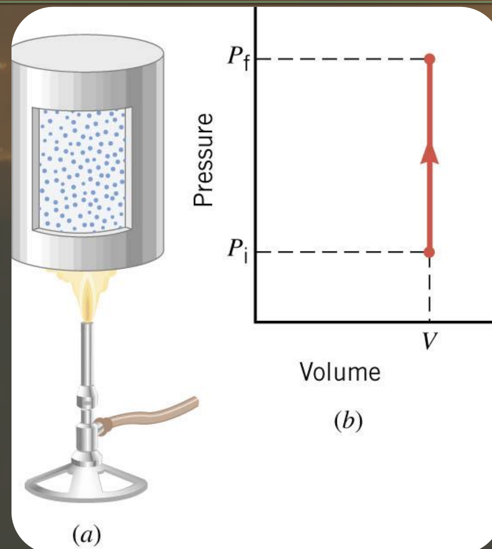
06-08 The 1st Law of Thermodynamics and Simple Processes

- Isobaric
  - Graph of V vs P
  - W = PΔV = area under graph



06-08 The 1st Law of Thermodynamics and Simple Processes

- Isochoric
  - Constant volume
  - Since no change in volume no work is done
  - 1st law of thermodynamics for isochoric processes
    - ΔU = Q – W, but W = 0
    - ΔU = Q



06-08 The 1st Law of Thermodynamics and Simple Processes

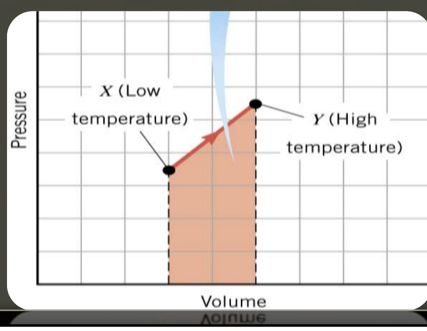
- Isothermal
  - Constant temperature
  - Usually temperature of a gas decreases as it (PV=nRT) expands, so thermal energy is transferred into the gas from the environment
  - $Q = W$

06-08 The 1st Law of Thermodynamics and Simple Processes

- Adiabatic
  - No heat transfer
  - 1st law of thermodynamics becomes
    - $\Delta U = Q - W$, but $Q = 0$
    - $\Delta U = -W$

06-08 The 1st Law of Thermodynamics and Simple Processes

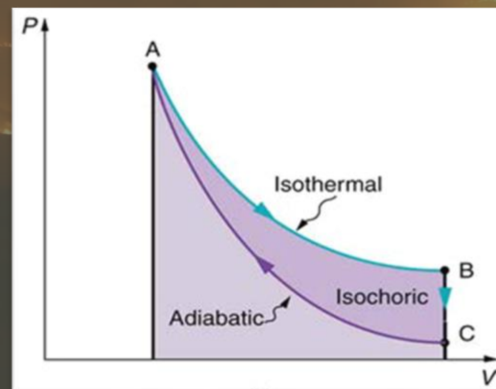
- Sometimes it is hard to determine the type of process
- A graph can help
- The area under a Pressure-Volume graph is the work



If volume increases W is +

06-08 The 1st Law of Thermodynamics and Simple Processes

- If the process goes in a loop, then the work done is the area inside the loop on a PV graph



The bottom portion cancels out
In this graph

- Isothermal is positive W
- Adiabatic is negative W since the ΔV is negative

06-08 The 1st Law of Thermodynamics and Simple Processes

- Since the work can be positive or negative, the processes can go either direction
- In theory it can be completely reversed (return to previous state)
- There is always friction so there is never completely reversible process

06-08 Homework

- I expect you to change the internal energy of the paper by doing work on it

- Read 15.3, 15.4, 15.5

06-09 The 2nd Law of Thermodynamics and Heat Engines

In this lesson you will…

- State the expressions of the second law of thermodynamics.
- Identify a Carnot cycle.
- Describe the use of heat engines in heat pumps and refrigerators.
- Demonstrate how a heat pump works to warm an interior space.
- Explain the differences between heat pumps and refrigerators.
- Calculate a heat pump's coefficient of performance.

06-09 The 2nd Law of Thermodynamics and Heat Engines

- Deals with spontaneous processes
- Heat spontaneously moves from high temp to low

06-09 The 2nd Law of Thermodynamics and Heat Engines

- Heat Engine
  - Uses part of the spontaneous heat transfer to do work
  - $W = Q_h - Q_c$
- Efficiency
  - $Eff = \frac{W}{Q_h}$
  - $= \frac{Q_h - Q_c}{Q_h}$
  - $= 1 - \frac{Q_c}{Q_h}$
- Only 100% efficient if no heat goes to environment

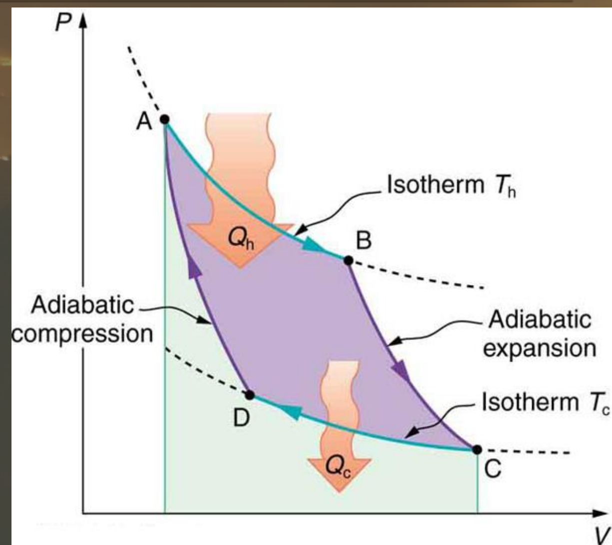
Q_c is heat sent to environment

06-09 The 2nd Law of Thermodynamics and Heat Engines

- Stated in terms of reversible processes, the **second law of thermodynamics** has another form:
- A Carnot engine operating between two given temperatures has the greatest possible efficiency of any heat engine operating between these two temperatures.
- Furthermore, all engines employing only reversible processes have this same maximum efficiency when operating between the same given temperatures.
- $Eff = 1 - \frac{T_c}{T_h}$

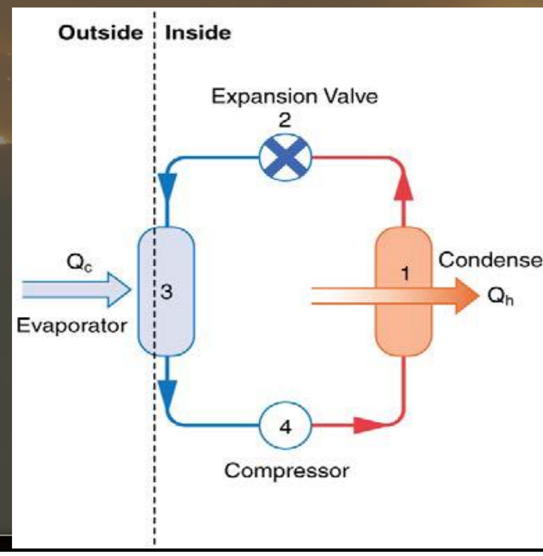
06-09 The 2nd Law of Thermodynamics and Heat Engines

- Carnot Engines use only reversible processes



06-09 The 2nd Law of Thermodynamics and Heat Engines

- Heat Pumps
  - Use Carnot cycle to move heat from low temp to high
  - 1. Gas at high temp/pressure in condenser, so heat goes to room
  - 2. Valve lowers temp/pressure turning gas to liquid
  - 3. Heat from cold area is used to evaporate liquid
  - 4. Compressor raises temp/pressure of gas



06-09 The 2nd Law of Thermodynamics and Heat Engines

- Heat pump
  - Coefficient of Performance
  - $COP_{hp} = \frac{Q_h}{W}$
  - $= \frac{1}{Eff}$
- Low Eff means high COP
- For a Carnot engine
  - $Eff = 1 - \frac{T_c}{T_h}$
  - Lowest Eff when $T_c \approx T_h$
  - Heat pumps work best when small temp difference

06-09 The 2nd Law of Thermodynamics and Heat Engines

- An automobile engine has an efficiency of 20% and produces an average of 23,000 J of mechanical work per second during operation. (a) How much heat input is required, and (b) how much heat is discharged as waste heat from this engine per second?

- $Q_h = 115\ kJ$
- $\frac{Q_c}{s} = 92\ kW$

$$Eff = \frac{W}{Q_h}$$

$$0.20 = \frac{23000\ J}{Q_h}$$

$$Q_h = \frac{(23000\ J)}{(0.20)} = 1.15 \times 10^5\ J$$

$$Eff = 1 - \frac{Q_c}{Q_h}$$

$$0.20 = 1 - \frac{Q_c}{1.15 \times 10^5\ J}$$

$$0.20 - 1 = -\frac{Q_c}{1.15 \times 10^5\ J}$$

$$(-0.80)(-1.15 \times 10^5\ J) = Q_c$$

$$Q_c = 92000\ J$$

$$Rate = 92\frac{kJ}{s} = 92\ kW$$

06-09 The 2nd Law of Thermodynamics and Heat Engines

- Refrigerators and Air Conditioners
- Similar to heat pump, but designed to cool

$$COP_{ref} = \frac{Q_c}{W}$$

- Since $Q_h = Q_c + W$,

$$COP_{ref} = COP_{hp} - 1$$

06-09 The 2nd Law of Thermodynamics and Heat Engines

- A heat pump has a coefficient of performance of 3.0 and is rated to do work at 1500 W. (a) How much heat can it add to a room per second? (b) If the heat pump were turned around to act as an air conditioner in the summer, what would you expect its coefficient of performance to be?

- $Q_h = 4500\ J$
- $COP_{ref} = 2.0$

$$COP = \frac{Q_h}{W}$$

Every second, W=1500 J since P=W/t

$$3.0 = \frac{Q_h}{1500\ J}$$

$$Q_h = 3.0(1500\ J) = 4500\ J$$

$$W = Q_h - Q_c$$

$$1500\ J = 4500\ J - Q_c$$

$$Q_c = 4500\ J - 1500\ J = 3000\ J$$

$$COP_{ref} = \frac{Q_c}{W}$$

$$COP_{ref} = \frac{3000\ J}{1500\ J} = 2.0$$

06-09 Homework

- Pump out some work about heat
- Read 15.6, 15.7

06-10 Entropy and the 2nd Law of Thermodynamics

In this lesson you will…

- Define entropy and calculate the increase of entropy in a system with reversible and irreversible processes.
- Explain the expected fate of the universe in entropic terms.
- Calculate the increasing disorder of a system.
- Identify probabilities in entropy.
- Analyze statistical probabilities in entropic systems.

06-10 Entropy and the 2nd Law of Thermodynamics

- Entropy
  - Amount of energy not available for work
  - Related to amount of disorder
- $\Delta S = \frac{Q}{T}$
  - ΔS = change in entropy
  - Q = heat transfer
  - T = temperature

06-10 Entropy and the 2nd Law of Thermodynamics

- 2nd Law of Thermodynamics
  - The total entropy of a system either increases or remains constant for any process; it never decreases.
- Spontaneous processes always result in
  - increase of entropy
  - less energy available to do work
  - $W_{unavail} = \Delta S \cdot T_0$

06-10 Entropy and the 2nd Law of Thermodynamics

- 1200 J of heat flowing spontaneously through a copper rod from a hot reservoir 650 K to a cold reservoir at 350 K. Determine the amount by which this irreversible process changes the entropy of the universe, assuming that no other changes occur.
- 1.6 J/K

$$\Delta S = \frac{Q_h}{T_h} + \frac{Q_c}{T_c}$$

$$\Delta S = \frac{-1200\,J}{650\,K} + \frac{1200\,J}{350\,K} = 1.6\frac{J}{K}$$

06-10 Entropy and the 2nd Law of Thermodynamics

- Find the change in entropy that results when a 2.3-kg block of ice melts slowly (reversibly) at 273 K (0 °C)
- $2.8 \times 10^3\ J/K$

$$\Delta S = \frac{Q}{T} = \frac{mL_f}{T}$$

$$\Delta S = \frac{(2.3\ kg)\left(3.35 \times 10^5\ \frac{J}{kg}\right)}{273\ K} = 2.8 \times 10^3\ \frac{J}{K}$$

06-10 Entropy and the 2nd Law of Thermodynamics

- Origins of Life
  - If the entropy (or disorderliness) increases, how do evolutionists justify evolution (more orderly)?
    - Need for something since they start by assuming God doesn't exist
    - When energy is put into something, it can decrease entropy for that thing, but total entropy of universe increases
    - They claim the sun gave energy to earth which allowed for life to spontaneously appear
      - This would mean spontaneously making something that absorbs energy to do unspontaneous processes (making less entropy)
      - This has never been duplicated in a lab

06-10 Entropy and the 2nd Law of Thermodynamics

- We use a similar idea, only we say God gave the energy and created highly organized creation
  - Ever since then, the creation has been falling apart

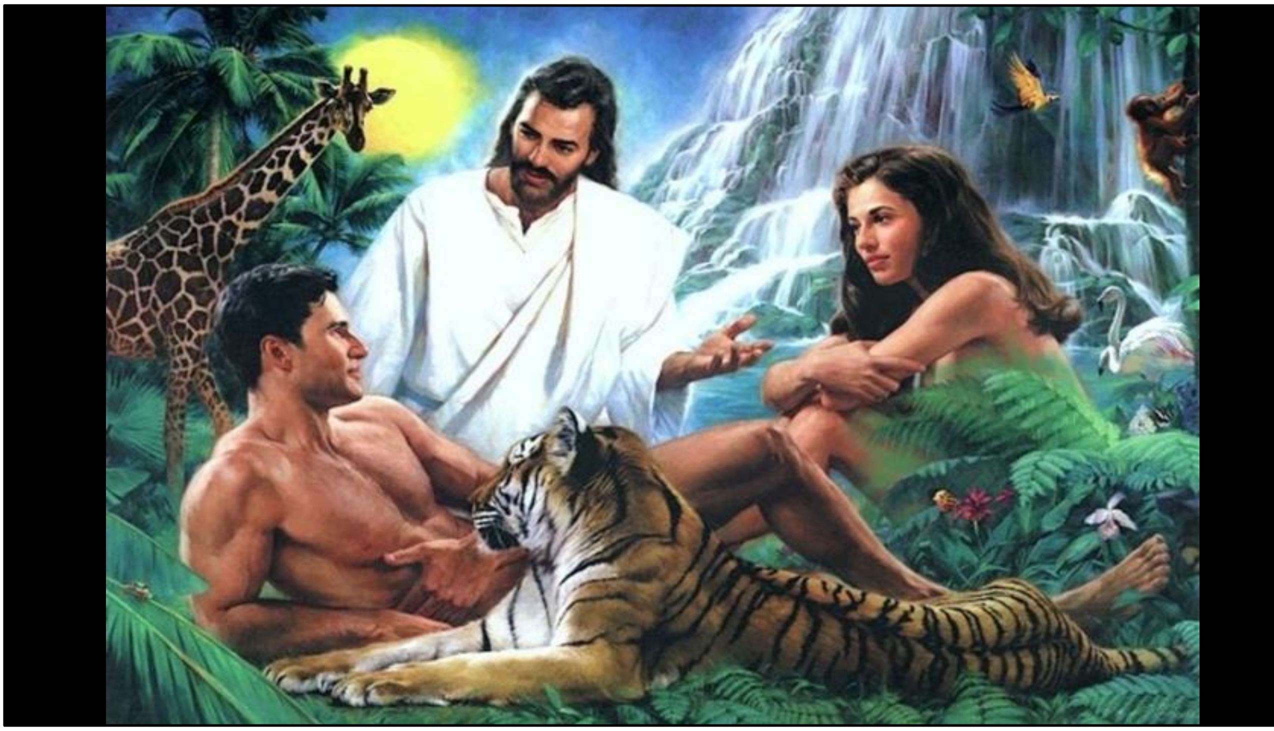
06-10 Entropy and the 2nd Law of Thermodynamics

- Why do spontaneous processes not decrease entropy?
  - A system can have several parts
  - All those parts have several ways they can be
  - Much more common to get less organized combinations
- Flip 5 coins
  - Macrostates
    - 5 heads
    - 4 heads, 1 tail
    - 3 heads, 2 tails
  - Microstates
    - HHHHH
    - HHHHT, HHHTH, HHTHH, HTHHH, THHHH

06-10 Entropy and the 2nd Law of Thermodynamics

- Entropy
  - $S = k \ln W$
  - $k = 1.38 \times 10^{-23} \frac{J}{K}$ Boltzmann's constant
  - W = number of microstates in system
- Using these statistics, life spontaneously developing is essentially impossible.
  - They say that since life exists, it must have happened
  - We say God made it happen

Whether or not you believe in God, you can be a good experimental scientist.



06-10 Entropy and the 2nd Law of Thermodynamics

- Do the lab handout.
- Entropy is the measure of the amount of energy unavailable to do work. Since energy is always lost in any process, the entropy always increases. Boltzmann suggested that entropy is a measure of the disorderliness of the universe. This is because disorder is far more probable than order when there is randomness.

06-10 Homework

- Help bring order to a disorderly universe.