

GS106 Class Notes - Matter, Energy, Heat

I. Matter / Composition of Matter (p. 182-193 in Hewitt Text)

A. Definitions

1. Matter- any material that occupies space and has mass.
2. Elements - all matter are made of elements, over 100 elements are known. Elements include O, Au, Ag, N, H, C and have a unique, and identifiable atomic structure.
 - a. Refer to periodic table in text
 - (1) 92 naturally occurring elements
 - (2) 11 man-made elements (103 total)
3. Compounds - combination of two or more elements joined together at the atomic level.
4. Atom - the smallest recognized particle of matter that retains the properties of a given element. Atoms of elements are combined together to form compounds.

B. Atomic Structure - Theory of atoms and atomic structure are based on experimental evidence and mathematical models. Atoms are generally too small to observe directly even with the most powerful microscope, but they can be observed indirectly by modeling.

1. Nucleus - central portion of an atom which contains even smaller sub-atomic particles called protons and neutrons.
 - a. Protons - very dense, positively charged subatomic particles in the nucleus of an atom.
 - b. Neutrons - dense, neutrally charged subatomic particles in the nucleus of an atom.
2. Electrons - negatively charged particles that orbit very rapidly about the nucleus of an atom. Generally considered that electrons are moving so fast, that it is difficult to locate their position at any given moment....view electrons as a cloud of charged particles hovering about the nucleus.
 - a. Electron clouds are organized at certain distances from the nucleus in regions called energy level shells. Each energy level shell at a given distance from the nucleus can only hold a certain number of electrons at any given time. An important fact with regards to attraction and bonding together of atoms to form compounds.
3. Atomic number - is the number of protons located in the nucleus, each element has its own unique atomic number making it distinct from other elements (e.g. C a.n. = 6, O a.n. = 8)
 - a. Isotope: same number of protons, variable no. of neutrons

(1) e.g. O18/O16: 8 protons but 10 and 8 neutrons respectively

4. Atomic charge balance - all atoms contain the same number of negative electrons as positive protons, thus as neutrons have no charge, then net positive charges = net negative charges (protons = electrons)

Elements can be considered to be large collection of electrically neutral atoms, having the same atomic number or no. of protons.

- C. Atomic Bonding - Chemical bonding between atoms occur when two or more elements join to form a compound (e.g. Na and Cl atoms typically bond to form NaCl or table salt). The forces that bring atoms or ions (electrically charged atoms) together are electrical in nature and the configuration of the electrons in the outer energy shell are important in relation to bonding characteristics of a given element.

II. States or Phases of Matter

- A. The state of matter is determined by the amount of vibrational energy at the atomic and molecular level

1. atoms / molecules possess kinetic energy
 - a. electron orbits
 - b. bond vibration

- B. Four States of Matter

1. Solid
 - a. Fixed "hard" shape to matter
 - b. atoms / molecules are in fixed positions
 - c. kinetic or vibrational energy is relatively low
2. Liquid
 - a. "fluid" material / changes shape easily; conforms to shape of container
 - b. atoms / molecules are mobile (not fixed / rigid)
 - c. higher kinetic / vibrational energy compared to solid
3. Gas
 - a. Even higher state of kinetic / vibrational energy
 - b. atoms / molecule separated
 - c. "fluid" material / "invisible" matter
4. Plasma
 - a. Highest state of kinetic energy
 - b. atoms vibrate apart
 - c. Result: free electrons and positive ions

- C. Other Stuff

1. Moral of Story: the state of matter is related to the amount of heat or vibrational energy associated with the system

The Higher the Internal Vibrational Energy --- the less Organized the Structure of the Material!

2. Density

Density = mass / volume (units: gm/cm³ or kg/m³)

a. Common Densities (gm/cm³)

(1)	Ice (solid H ₂ O)	0.92
(2)	Water (liquid H ₂ O)	1.0
(3)	Quartz	2.65
(4)	Lead	10.5
(5)	Benzene	0.81
(6)	Seawater	1.03
(7)	Dry air (0 C)	0.00129
(8)	Hot air (30 C)	0.00116

IMPORTANT CONCEPT: Less dense objects will float in more dense liquids; more dense objects will sink in more dense liquids.

Density determines the nature of "floaters" and "sinkers"

Questions for Thought:

Given the density of lead above, if you had 21 gm of lead, what would its volume be?

Which has a greater density: 1000 kg of Benzene or 1 kg of Lead?

Will ice float in water and why?

Does lead float or sink in water and why?

Consider a freshwater river flowing into the ocean, what will happen to the river water once it flows into the ocean? and why?

Why does a hot air balloon rise in the atmosphere?

III. Heat Energy and Temperature

A. Heat - internal energy within a substance = kinetic molecular energy

1. high heat substances = high degree of kinetic molecular energy

a. i.e. the higher the heat the faster the vibration of atoms and molecules

B. Temperature - measure of the average amount of heat energy in a substance - i.e. the average kinetic energy of a substance

a. Metric unit = Celsius, English unit = Fahrenheit

(1) Measured in terms of freezing and boiling points of water

(2) water freezes at 32° F = 0° C water boils at 212° F = 100° C

b. Conversion Factors:

- (1) From C to F: $F = \frac{9}{5}C + 32^\circ$
- (2) From F to C: $C = \frac{5}{9}(F - 32^\circ)$

- (a) E.g. convert 40 C to F
 $F = \frac{9}{5}(40) + 32 = 104^\circ \text{ F}$

c. Degrees Kelvin

- (1) measured in terms of heat energy
- (2) Zero K = "Absolute Zero"
 - (a) State of Zero Kinetic Energy
 - (b) -273° C
- (3) Degrees K = Degrees C + 273
 - (a) so $0^\circ \text{ C} = +273^\circ \text{ K}$

Sooooo... temperature is a measure of heat, which is in turn equal to the amount of molecular kinetic energy in a system or substance

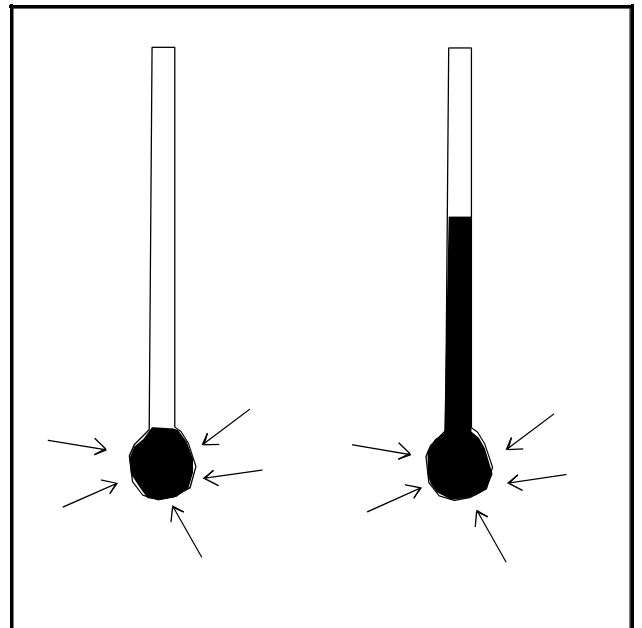
The higher the temperature... the faster the rate of atomic/molecular vibration!!!

1. Thermometers

a. e.g. thermometer in air:

- (1) heat of air is transferred to the thermometer
- (2) heat of thermometer causes > vibration
- (3) > vibration / > heat causes fluid in thermometer to expand and rise up the glass tube

b. Thermometers measure the average molecular kinetic energy of a substance
NOT THE TOTAL KINETIC ENERGY IN THE SYSTEM



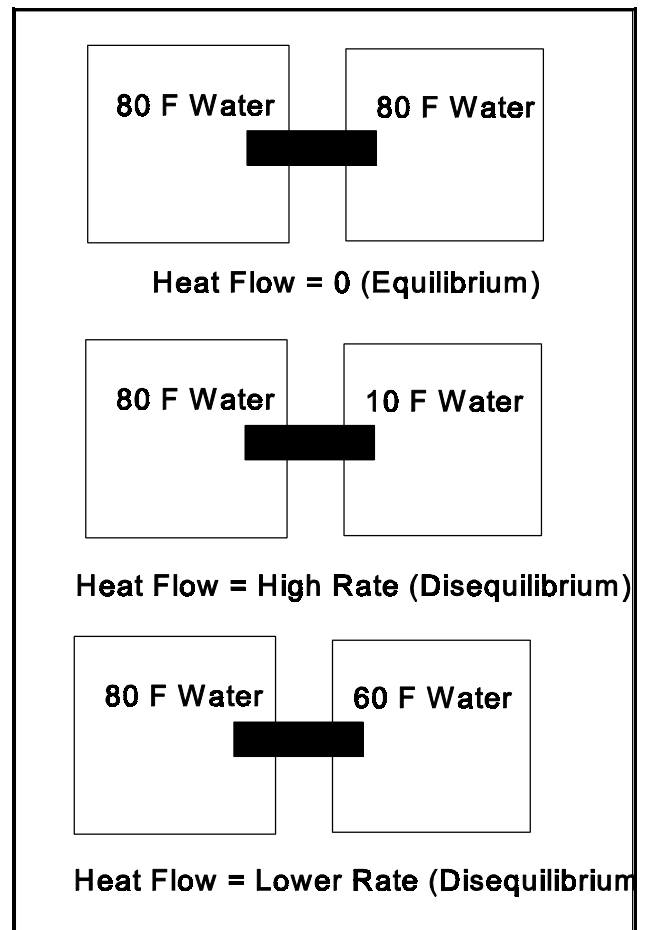
LOW AVERAGE KINETIC ENERGY = LOW TEMP.

HIGH AVG. KINETIC ENERGY = HIGH TEMP (Fluid in Thermometer Expands)

C. Heat Flow

1. "Thermodynamics" = study of heat, heat flow and behavior of heat
2. Heat Flow : An Equilibrium Process
 - a. Temperature Imbalance Causes Heat to Flow or Transfer
 - b. Substances at Same Temperature = Temperature Equilibrium
3. Heat Flows from High Temperature Regions to Low Temperature Regions
 - a. At temperature equilibrium: net heat flow = 0
 - b. The higher the temperature differential, the faster the heat flow
 - c. The lower the temperature differential, the slower the heat flow

Consider an experiment with two vessels of water, with variable heat-content. They are connected by a tube that allows heat to exchange between the two vessels.



- d. Specific Heat Capacity
 - (1) Amount of heat required to raise the temperature of 1 gram of a substance, 1 degree C

- (2) E.g. Water has high heat capacity compared to rock
 - (a) takes a higher amount of heat to raise the temperature of water, compared to rock
 - (b) Result: water heats and cools more slowly than earth /rocks

D. Heat, Expansion, Contraction

1. Expansion of Hot Matter
 - a. Increase heat, increase temperature, increase vibrational kinetic energy of atoms / molecules
 - (1) atoms/molecules vibrate faster - move farther apart to make room
 - (2) Net Result: Expansion and Volume Increase
2. Contraction of Cold Matter
 - a. Opposite Relation: remove heat, < temperature ... volume decrease / contraction
3. Density Relations to Heat-Induced Volume Changes
 - a. Density = mass / volume
 - (1) assuming mass is constant, when volume decreases, density increases
 - (2) assuming mass is constant, when volume increases, density decreases
 - (a) i.e. an "inverse relationship" between density and volume
 - b. Heat Loss = Cooling = < kinetic energy = < volume = > density
 - c. Heat gain = Warming = > kinetic energy = > volume = < density
 - (1) e.g. Hot Air Balloon: Hot Air = volume increase = density decrease
 - (a) less dense hot air rises relative to more dense cold air
4. States of Matter vs. Volume Change / Density Change
 - a. Solids = decreased temperature = decreased kinetic energy = decreased volume = increased density
 - b. Gases = increased kinetic energy = increased volume = decreased density
 - c. e.g. Mercury (Hg)
 - (1) Density of Solid Hg > Density of Liquid Hg > Density of Gaseous Hg
5. Special Consideration: Water
 - a. Most substances are more dense in a solid state compared to a liquid state
 - b. Water is the opposite
 - (1) Density of Ice (solid water) = 0.92 gm/cm³
 - (2) Density of Water (liquid) = ~1.0 gm/cm³
 - (a) Result: Ice Floats in Water
 - (3) Why? Because the crystal structure of ice takes up more space (greater volume) than the structure of liquid water molecules

- c. Importance: A good thing, otherwise oceans and lakes would freeze from the bottom - up... resulting in destruction of all aquatic life!!!
 - (1) Luckily: Lakes / oceans freeze with ice on the surface, and liquid water insulated from freezing at depth.

IV. Heat Transfer

A. Mechanisms of Heat Transfer

- 1. Conduction: heat and vibrational kinetic energy is passed from molecule to molecule, without actual transfer of mass
 - a. heat transfer without mass transfer
 - b. e.g. heating an iron rod, the heat is transferred from one end to the other without transfer of mass
 - c. Examples
 - (1) Good conductors of heat = iron / metal (rapidly transmit heat)
 - (2) Poor conductors of heat = adobe / brick, fiber glass insulation
 - (a) Poor conductor = "good insulator"

Question: which would you rather have in Death Valley, CA: A house made out of 5 ft thick adobe walls, or a house made out of tin / sheet metal?

How about in Alaska?

- 2. Convection - heat transferred via transfer of mass
 - a. e.g. "fluid currents" transfer heat
 - b. Convection cells common in ocean, atmosphere, and earth's interior
 - (1) e.g. Warm air rises, cools, sinks
 - (2) e.g. Warm ocean water rises, cools, sinks
- 3. Radiation - heat transfer via electromagnetic radiation
 - a. infrared radiation = "thermal radiation"
 - (1) remember: infrared = wavelengths longer than visible spectrum
 - b. Emitters of radiant energy
 - (1) Sun (hydrogen fusion)
 - (2) Earth (radioactive decay of elements)
 - c. Absorbers and Emitters of Radiation
 - (1) Good Absorbers are Good Emitters
 - (a) e.g. black paper experiment in lab

- i) black objects cool and warm faster
 - ii) black is a poor reflector of energy
- (2) Poor Absorbers are Poor Emitters
 - (a) e.g. white paper experiments in lab
 - i) white objects cool and warm slower
 - ii) white reflects radiant energy
- (3) All materials absorb and emit radiation at the same time

Question: can heat be transferred through space by conduction or convection?

remember space is a vacuum of virtual nothingness

How about radiation?

V. Phase Changes / States of Matter ---- It's all in the heat content

A. Case Study: Water as a Solid, Liquid, and Gas

1. Three states of matter
 - a. gas
 - b. liquid
 - c. solid
2. Unlike N, O and CO₂ (stable gases at all earth surface temps); water vapor is very temp. sensitive and readily changes states depending on heat energy in atmospheric system

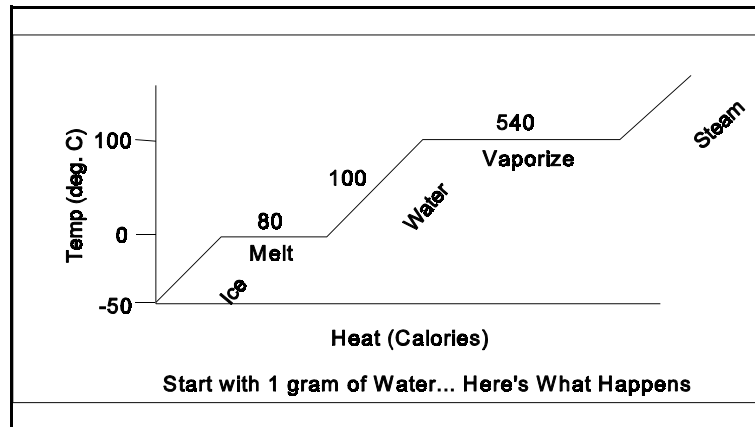
B. Water Vapor and States

1. Evaporation- converting liquid water to water vapor-gas (requires heat / uses heat)
2. Condensation- converting water vapor/gas to liquid (releases heat / gives off heat)
3. Freezing- converting liquid water to solid ice
 - a. Melting- solid changed to liquid
4. Sublimation- converting water vapor/gas directly to solid ice

C. Thermal Budget and States

1. States of matter a function of amount of heat in system, which in turn influences the vibrational rates of molecules
 - a. gas - high rate of vibration, high heat condition
 - b. liquid- medium rate of vibration, medium heat system
 - c. solid- low rate of vibration, low heat system
2. Heat Energy
 - a. measured in calories
 - (1) amount of energy required to raise the temperature of 1 gram of water 1 degree C
3. Heat and State Transformation
 - a. Evaporation: water liquid to vapor = system must absorb 600 Cal of energy
 - (1) energy absorbed by molecules, > rate of vibration to allow phase change
 - (2) latent heat of vaporization = "stored heat" that is exchanged to cause phase change

- b. Condensation: water vapor to liquid = system must lose 600 Cal of energy
- (1) < vibratory motion
 - (2) latent heat of condensation
 - (3) Condensation/heat transfer
 - (a) drives storm systems
 - (b) affects climate
 - (c) transfers heat from equator to poles
 - (d) results n cloud phenomena
- c. Melting: solid ice changed to liquid = system must gain 80 calories of energy
- d. Freezing: liquid to solid = system must lose 80 calories of heat energy
- e. Sublimation: solid to gas or gas to solid = system must gain 680 cal of energy or lose 680 cal of energy respectively for transformation to occur
- (1) e.g. dry ice sublimates to gaseous carbon dioxide with no intervening liquid phase



4. Moral of Story:
- a. Energy is released going from a gas to liquid to solid (heat given off)
 - b. Energy is absorbed going from a solid to liquid to gas (heat absorbed)