# Outline for 1st year Modeling Chemistry Course – v9 – 8/3/06

| Phenomena/Investigations/Activities | Concepts/Theories/Tools |
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| **1. Physical properties of matter-intro to a simple particle model** | **Modeling Tools** |
| **1.1 Mass** | |
| **Measurement of mass**<br>standard unit of mass, unit conversions, use of balance – scientific notation | Measure of how much "stuff" is present in a sample<br>Measured by a balance (SI unit = kg, chem unit is gram) |
| **Mass and change**<br>Mass of steel wool (compacted vs expanded)<br>Mass of heated steel wool<br>Mass of ice and water<br>Mass of a precipitate<br>Mass of dissolved sugar<br>Mass of dissolved Alka-Seltzer | Mass is conserved in all sorts of physical and chemical changes, provided that nothing enters or leaves system<br>Students compare mass before and after, report class data, represent change with histograms. They model what they think is happening at the atomic level. Matter composed of very tiny hard balls (BB's). Size and mass of balls for each kind of stuff vary, but the total number of balls remains constant. Macroscopic changes come from rearrangement of the BB's.<br>Introduce particle diagrams to describe change<br>Show Ring of Truth-episode 2: Change |
| **1.2 Volume**<br>**What is volume and how is it measured?**<br>**Compare units of volume**<br>Calculate volume of water in container, measure with grad cyl.<br>Graph volume in mL vs volume in $cm^3$ | Volume defined as number of unit cubes that fill container.<br>Measured with graduated cylinder (liquid) or by displacement (solid)<br>Calculated from measurements of length, width, height<br>Changes depending on the state of matter<br>Use Logger Pro to plot data; slope of line (1.0 mL/$cm^3$) is unit conversion. |
| **1.3 Density**<br>**Relationship between mass and volume**<br>measure mass & volume of different samples of two different materials (Al and Fe)<br>**Density of solids and liquids – characteristic property** | Since we now know that $cm^3$ and mL are equivalent, volumes of metals can be found by displacement<br>Plot mass vs volume using Logger Pro – slope has physical meaning<br>→ density, another conversion factor<br>Does particle model of matter account for differences in density of solids? It's hard to tell. But we can account for the fact that most solids are more dense than their corresponding liquids. Introduce concept that density is a property of the substance, not the object. |

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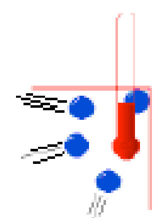
| **Density of a gas**<br>Dissolve Alka-Seltzer in water, collect gas by water displacement | Find mass of gas indirectly, calculate density, compare to accepted value<br>Modify particle model to account for fact that the density of gases is so much smaller than that of solids or liquids |
| **Thickness of a thin layer**<br>Use tools we have thus far (V=M/D, h = V/A) to calculate the thickness of sheet of Al foil –this gives an upper limit for size of atoms. Have students estimate, then calculate the number of layers of atoms in a sheet of Al<br>Website: Size of things allows students to elate SI prefixes to items of smaller and smaller size, down to the size of molecules | Ring of Truth Video #5 Atoms - Rolling out gold leaf, pouring of oil onto pond<br>Introduce concept of uncertainty in measurement. Need to have number of expressed digits imply something about the quality of the measurements<br>Sig fig rules provide a way of keeping an appropriate number of digits in calculated quantities<br><br>Use of conversion factors to change from one unit to another |
| **2. Energy & the states of matter-part 1**<br>**2.1 Characteristics of gases, liquids and solids, Kinetic energy & temperature**<br>Demo/discussion: diffusion of gases<br>Demo/discussion: diffusion of dyes in hot and cold liquids<br>Kinetic energy ($E_k$)- depends on mass and velocity | **Structure of Matter → Energy**<br>**Intro Kinetic Molecular Theory**<br>All matter is composed of tiny particles in constant random motion. Particles must be moving in order for diffusion to occur. Hotter particles must be moving faster.<br>Show video series: Eureka – Heat & Temperature<br>#1 molecules in solids, #2 molecules in liquids, #3 evaporation and condensation |
| **Demo: Thermal expansion of liquids**<br>Heat water and alcohol in tubes with capillaries to amplify expansion | Temperature is a measure of the average kinetic energy of particles. At a given temperature, lighter molecules move faster.<br><br>Transfer of energy to a liquid speeds up particles, causes a change in volume. How a thermometer works Eureka episodes #4 expansion and contraction, #5 measuring temperature, |
| **2.2 Behavior of gases**<br>gas pressure –> molecular collisions<br>measurement of pressure, various units, standard pressure | Function of and reading barometer, manometer<br>Pressure is a measure of the force exerted by gas particles, "Blow up the student" demo<br>"Suction" due to pressure difference – show how "Shop-Vac" works<br>crush the can demo |

**PVTn lab**
Part 1 – Pressure vs. volume. Use pressure sensor to record pressure at various volumes, plot P vs V, linearize to show inverse relationship
Part 2- Pressure vs. number. Record pressure at 10 mL, open syringe to atmosphere, change volume of air in syringe (and thus # of particles), reconnect syringe to pressure sensor, restore volume to 10 mL and record pressure. Plot P vs. n.
Part 3 – Pressure vs. temperature. Immerse flask with pressure sensor in water baths ranging from boiling water down to freezing water. Record pressures, plot P vs T. Extrapolate line to find absolute zero.

**PVTn problems**
Use factors to convert P, V, n or T at one set of conditions to another. Explain effects in terms of motion of particles.

# 3. Energy & the states of matter-part 2

## 3.1 Phases changes

**Icy Hot**
Record temperature of ice until solid has melted, warmed to 100˚C, then boiled for 3 minutes. Plot T vs time, describe what occurs physically and energetically in all three regions of the graph.

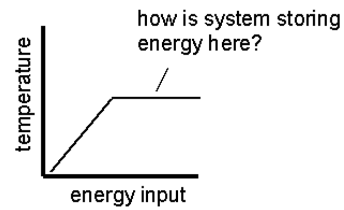
**Freezing of a liquid (other than water)**
Cool molten lauric acid until it freezes, graph T vs time
Emphasize freezing as process – does not necessarily mean cold

**3.2 New energy accounts:**
Interaction energy ($E_i$) – attractions between particles
Chemical energy ($E_{ch}$) – attractions between the smaller particles that make up "compound particles" (unit 4)

Pressure is inversely proportional to volume. Pressure is proportional to the number of particles. Pressure appears to be proportional to temperature, but only if the zero on temperature scale is moved to point where volume shrinks to zero – absolute zero. If temperature is a measure of molecular motion, then absolute zero is temperature at which motion ceases. Celsius zero is arbitrary, Kelvin is a "natural" temperature scale.

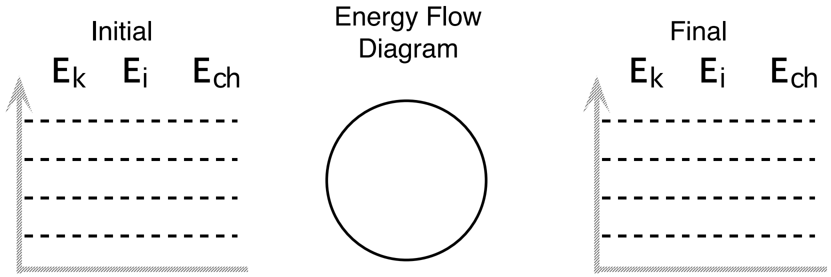
Represent particles in motion at three places on P vs V, P vs n and P vs T graphs.

Rather than use $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$ to solve for missing variable, have students make a decision about how the change will affect the starting quantity, then multiply by appropriate factor; e.g., if pressure **increases** from 730 mm to 760 mm, then volume will be **reduced** by factor $\frac{730}{760}$.




How is system storing energy during plateau regions on graph? Our particles must be "sticky"; i.e., they exert attractions on each other.
Surroundings supply energy required to break down structure of solid, allow molecules freedom of moving freely past one another, even though the molecules still feel attractions.
During melting, the temperature of the sample (ave $E_k$) remains constant, so energy transferred must be stored in the arrangement of the particles. Postulate a new energy account: interaction energy ($E_i$) that can store energy in a system. Identity of the individual particles remains unchanged. Freezing is the reverse process of melting. Molecules in liquid phase must give up interaction energy to surroundings in order to settle down into orderly structure in the

Introduce energy bar charts to keep track of how system stores energy during phase changes and of exchanges between system and surroundings




Attractions between molecules *lower* their energy. Separating molecules requires energy input to overcome attractive forces. In phase changes, interaction energy is involved. See Energy Reading

**Quantitative treatment of energy (heat of fusion, vaporization)**

After students have solid conceptual foundation of energy storage and transfer, they learn to calculate how much energy is involved in change.

solid state.

"Potential" energy briefly discussed in most texts is subdivided into two storage modes ($E_i$ and $E_{ch}$) depending on range and nature of particles exerting attractions. See PowerPoint presentation Energy in Chem-1a

Heating, working and radiating are described as *processes* by which energy is transferred into or out of system. Energy bar charts help keep track of energy storage and transfer.(ws 2.doc, and **ws 3.doc**) Emphasis is placed on where energy comes from or goes to.

Energy transfers cause liquids to boil. How does our particle model account for this? When gases re-combine, energy is released- why? What occurs during evaporation at temps lower than bp? What is the composition of gas in a bubble forming in boiling water?

Heat capacity introduced as a factor relating Q to mass and temperature change. Quantitative problems can be solved without resorting to equations that students use by rote.

# 4. Describing substances- particles have some internal structure

## 4.1 Pure substances vs mixtures

Compare cooling curves/boiling curves for pure substances and mixtures

Pure substances have one set of characteristic properties, well-defined plateau for freezing/melting or boiling, mixtures not so well defined.

## 4.2 Evidence for compound particles

**Electrolysis of water**

Water, a pure substance, can be broken down into two different pure substances which combine in a fixed ratio.

The simple particles we have used thus far must be composed of simpler particles. For many students this demonstration provides the first hard evidence for why we write water as $H_2O$. Show video clip from *The Ring of Truth – Atoms*. Philip Morrison says, "Something about these atoms knows some arithmetic."

## 4.3 Evidence for electrical charge in particles

**Sticky-Tape Lab**

Students examine attractions and repulsions between charged pieces of tape and other materials.

Observations are the basis for a model of the atom with a positive inner core and mobile, negatively charged electrons.

The behavior of charged objects results from uneven charge distribution. An attraction between two objects is evidence for an excess of charge on at least one object. Either:

a. objects have excess charge of opposite type, or

b. one charged object induces a charge imbalance in a neutral object (polarization).

Repulsion between two objects indicates that both objects have an excess of the same type of charge.

The simple particle model used thus far needs further structure in order to account for observed behavior.

**Conductivity demo/discussion**

Conductivity of solution of ionic vs molecular solids

It's actually best to discuss conductivity of the **melt**, but this is not easily done in the high school lab. Students can use inexpensive conductivity probes to compare conductivity of a variety of solutions

## 4.4 Pure substances are atomic, ionic or molecular

Explain observed behavior (mp, conductivity of melt and solutions) in terms of basic unit of structure

Substances that are not simply atomic are either molecular or ionic. If the basic unit of structure is the molecule, then the solid is a collection of discrete molecules with relatively weak intermolecular attractions. The melt will not conduct electricity although an aqueous solution may conduct (see HF).

If the substance is ionic, then the solid is a lattice of charged particles, each of which is attracted simultaneously to several nearest neighbors. There are very strong interactions between the ions, so the mp is usually much higher than that of molecular solids

## 4.5 Nomenclature and formulas

Now, a reason exists for different naming conventions.

Rules for naming depend on whether the substance is molecular or ionic.

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| 5. Counting particles too small to see | |
| **5.1 Counting by weighing**<br>**“Count” BB’s in a jar, grains of sand in a sample** | Atoms and molecules are much too small to count individually. We must have a way of counting them by weighing a sample. |
| **5.2 Avogadro’s Hypothesis & relative mass**<br>**Combining volumes of gases** | Evidence for Avogadro’s Hypothesis – gases combine in simple integer ratios (one $NH_3$ + one HCl, two $H_2$ + one $O_2$) – most easily explained if equal volumes at same T and P contain equal numbers of molecules.<br>CHEM-STUDY video: *Gases and How They Combine* |
| **Relative mass, counting by massing**<br>Find mass of equal quantities of various kinds of hardware, compare masses to lightest item, determine relative mass of each piece. Perform calculations to find the mass equivalent to a very large number of pieces. | Molar masses in Periodic Table originally based on masses relative to hydrogen; later the C-12 standard was adopted.<br>This activity provides foundation for mass→ moles calculations<br>Representations of N, see JChemEd article |
| **5.3 The mole concept**<br>**Molar mass , mass→ mole→ particles calculations**<br>Molar masses in Periodic Table based on relative masses<br>Practice using factors to convert g → moles and back again | |
| **5.4 Empirical and molecular formulas**<br>**Empirical formula lab**<br>Use varying amounts of Zn in xs HCl, find ratio $\frac{moles\ Cl}{moles\ Zn}$ | |
| Compare to accepted formula from nomenclature rules | Comparing class results show that despite the fact that the moles Zn reacted varied from group to group, the mole ratio remained constant. |
| **Empirical and molecular formula problems**<br><br>**Per cent composition problems** | The experimental evidence provides basis for the combining powers described earlier. |

# 6. Chemical Change- Particles and Energy

## 6.1 Representing chemical reactions

**Making products from reactants**

Given unbalanced equations, use colored disks to represent atoms in molecules of reactants. Rearrange the “atoms” to form product molecules – no “leftovers”. Write in coefficients to balance the equation.

**Balancing chemical equations**

**Relating equations to descriptions of reactions**

### Keeping track of atoms in chemical change

The trouble with the standard representation is that it shows both reactant AND product molecules existing simultaneously. It does NOT convey the notion that in order to make the product, the reactant molecules must be *consumed*; i.e., the atoms must be rearranged for the products to form. For students, the arrow does not necessarily convey the notion of “before” and “after”.
See Rep Chem Rxns.doc

Once students understand chemical rxns involve rearrangement of atoms which are conserved, the standard balancing exercises can be done. Remind students that atoms are conserved but molecules are not.
Emphasis is placed on easily moving between verbal, diagrammatic and symbolic representations of chemical change.

## 6.2 Types of Chemical Reactions

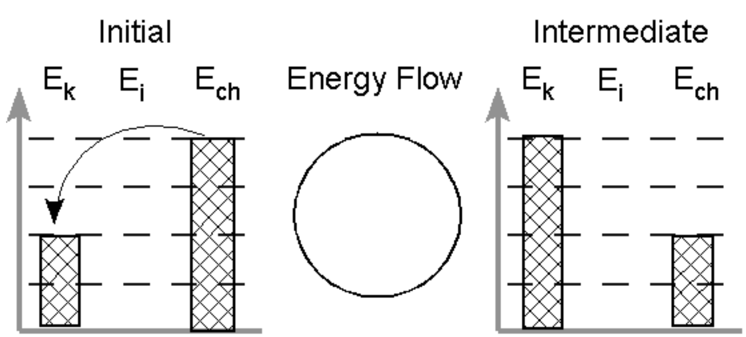
**Lab: Types of chemical reactions**

Students observe and categorize several kinds of chemical change, then learn to generalize to wider group of reactions

This same lab sets up the discussion of the role of energy in chemical change. Students have to explain whether reactants or products store more chemical potential energy

## 6.3 Energy effects in chemical reactions

Bonds do not “store energy.” Separating atoms in molecules (or ions in a lattice) always requires energy. When atoms combine, energy is released. Chemical energy is the storage mode for interactions between atoms or ions.




### Keeping track of energy in chemical change

Revisit energy bar charts to treat this energy storage mode.
Some molecules store more energy than others. When atoms in reactant molecules are rearranged to form product molecules, the chemical potential energy in the system changes. This results in a change in the kinetic energy of the molecules in the system.

Bar graph at left represents **exothermic** reaction. Due to the increase in the kinetic energy, the temperature of the system rises. This results in the eventual transfer of energy (via Q) from the warmer system to cooler surroundings.
The treatment of energy at this stage is qualitative.

# 7. Stoichiometry I - mass

## 7.1 Quantifying change using mole ratios

**Fe-$CuCl_2$ lab**

Replacement reaction in which Fe is xs reactant. Mole ratio enables students to write a balanced equation to describe the reaction.

**Mole ratios – BCA table**

Students write before, change and after beneath balanced equation to predict mole ratios based on coefficients. Primacy of working with moles is emphasized.

**Further practice involving mass, % yield and limiting reactants**

**Cu-$AgNO_3$ lab**

Replacement reaction in which Cu is xs reactant. Silver obtained in this lab is converted back to $AgNO_3$ and then to AgCl in subsequent lab

**Making quantitative predictions of the outcomes of chemical reactions**

Students describe what they believe was happening to the atoms of iron and copper during the reaction. They must decide if the ratio of copper to iron would change if they had placed more nails in the beaker, or permitted the reaction to go for less time.

Standard grams → moles → moles → grams algorithm promotes mindless plug-n-chug approach which works in limited number of cases. BCA approach (see BCA.ppt) emphasizes connection between coefficients and mole ratios, requires students to make decisions about what is consumed and what remains. BCA table is applicable for all sorts of problems including limiting reactant, problems with gases and molar volume, solution stoichiometry, and equilibrium.

# 8. Stoichiometry II – volume & energy

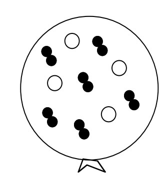
## 8.1Partial pressure

Pressure of each gas in a mixture proportional to the number of particles of that gas.

**Molar volume of a gas lab**

React Mg with HCl, collect $H_2$ over water, determine volume of a mole of $H_2$ gas.

Now that students have a firm grip on the mole, re-visit gases. Since pressure is a function of molecular collisions, partial pressure is related to mole fraction. Show representations of molecules in a gas mixture.



This lab requires students to use partial pressure, PVT conversions and stoichiometry (mole ratios) to determine the molar volume for $H_2$. Molar volume is gaseous analog to molar mass – even more useful since it is essentially the same for all gases (assuming ideal behavior).

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| **8.2 Gaseous stoichiometry problems**<br>Introduce ideal gas equation, use to solve for moles with gases. | Use lab data to determine value of R. Given PVT data, solve for $n = \frac{PV}{RT}$, then use mole ratios as before. |
| **8.3 Stoichiometery –solutions**<br>**Molarity – solution stoichiometry**<br>Means to determine moles when substances are in solution.<br><br>**Molar concentration problems** | Many chemical reactions take place in aqueous solution. It is useful to be able to determine the number of moles of reactants or products present in solutions. |
| **8.3 Quantifying energy transfers during chemical change**<br>**Heat of combustion lab**<br>Burn candle, heating water. Use $Q = mc\Delta t$ to determine energy transferred to water; calculate ΔH (kJ/mole) for combustion of paraffin.<br><br>**Energy stoichiometry problems**<br>Series of questions treating the quantity of energy involved when atoms are rearranged as a part of the balanced chemical equation. | Use of energy bar charts to describe energy exchanges between system and surroundings provides logical basis for sign convention of ΔH. Students still employ BCA table to relate energy to mole coefficients in balanced equation. |