Professor K

Stoichiometry

How can we represent the law of conservation of mass?

- CHEMICAL EQUATIONS are the shorthand used.
- Don’t forget, chemistry is a second language! Look up any words you don’t understand, and get a full, conceptual understanding of them.

Molecular mass

- The sum of the atomic masses of the atoms in a compound
- Ex- CO_2 is 12.011 + 2(15.9994) AMU
- Ex- $Mg(NO_3)_2$ is 24.3050 + 2(14.0067 + 3(15.9994))
- FORMULA MASS is not a topic we will discuss in detail yet as it refers to ionic (as opposed to molecular) compounds

The mole

- Just a number, like “pair,” “dozen” or “gross”
- Abbreviated “mol” NOT “m” or “M” which are the abbreviations for meter and molarity, respectively

Moles

mole

molé

The mole

- Number of atoms in exactly 12g of cabon-12 ...same number as in 16g of oxygen-16, 1g of hydrogen, etc.
- 6.02×10^{23} = Avogadro's number = HUGE number (six hundred two sextillion)
- 602,214,000,000,000,000,000,000
- How huge is it?.....

Why do we use the mole?

- 1 dozen cars = 12 cars
- 1 mole of cars = 6.02×10^{23} cars

- 1 dozen Al atoms = 12 Al atoms
- 1 mole of Al atoms = 6.02×10^{23} atoms

- The NUMBER is always the same...
  - The MASS is very different!

- Chemistry often deals with extraordinarily big or small numbers.
- We use numbers we can deal with in everyday life.

A mole is BIG

- If everyone on Earth bought stuff off the dollar menu (with 1 mole of dollars for the whole planet), everyone could order approximately 100 trillion items
- We could do the $700B bailout 700 billion times and still have only used 80% of 1 mole of dollars
- If a mole of pumpkins is split into 16 piles, each is the size of Earth
- Assuming 1 rat per person in NYC (disproven), it would take 73 billion million cities to get a mole of rats

How big is it?

The mole – more fun

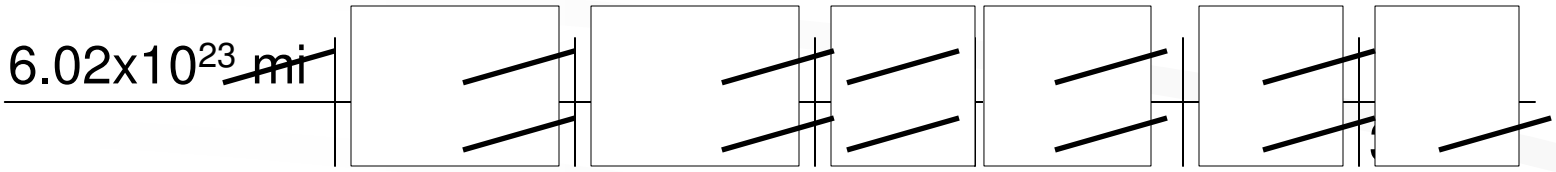
- If you spent $1billion/sec your whole life, you'd have spent less than 0.001% of a mole of dollars
- A mole of pennies distributed equally to everyone on Earth gives everyone approximately $1trillion
- A mole of peas would cover the Earth to a depth of 100m
- A mole of marshmallows would cover the Earth to a depth of 12 miles
- A mole of oranges weighs as much as the Earth
- A mole of papers would stack from the Earth to the moon and back 80,000,000 times

How do we use the mole?

- UNITS, UNITS, UNITS!!!!
- If your units are correct, the answer will be correct.
- Use dimensional analysis, factor labeling, whatever you want to call it, to convert what you are given into what you are asked for.

Problem #1

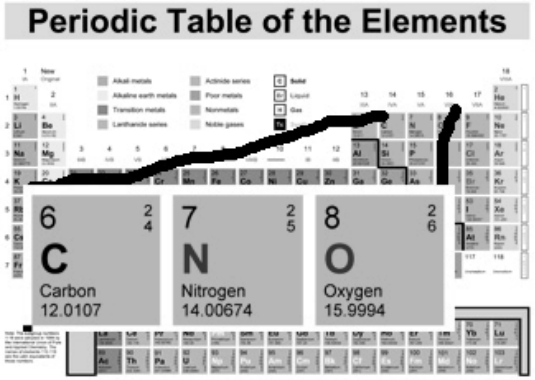
- How many light years is a mole of miles?



- 1.02×10^{11} light years (102 billion)

Molecular mass – a review

- The sum of the atomic masses (from the periodic table) of the atoms in a compound
- CO_2 is 12.0107 + 2(15.9994) ≈ 44 AMU



- Why use the mole?
- If you have one mole's worth of atomic mass units, you have one gram...

$$(1.66 \times 10^{-27}\ \text{kg}) \times (6.02 \times 10^{23}) = 1.00\ \text{gram}$$

Problem #2

- Prove that 6.02×10^{23} MOLECULES of CO_2 is 12 + 2(16) GRAMS

$$\frac{6.02\times10^{23}\ \cancel{CO_2}}{1\ \cancel{CO_2}} \left| \frac{44\ \cancel{AMU}}{1\ \cancel{AMU}} \right| \frac{1.66\times10^{-27}\cancel{kg}}{\cancel{kg}} \left| \frac{1000g}{} \right. = 44g\ CO_2$$

- The MASS of one MOLE of atoms or molecules is equal to the numbers from the periodic table added together in GRAMS
- N_A = number of atoms in exactly 12g of carbon-12 ...same number as in 16g of oxygen-16, 1g of hydrogen, etc...

Problem #3

- How many moles of Cu are present in 22 pennies with a mass of 60.0 g, assuming the penny is 100% Cu?

$$\frac{60.0\ \cancel{g\ Cu} \quad | \quad 1\ \text{mol Cu}}{\quad | \quad 63.5\ \cancel{g\ Cu}} = 0.945\ \text{mol Cu}$$

Molar mass

- The mass of one mole of atoms or molecules
- Ex- CO_2 is 12.011 + 2(15.9994)
  GRAMS = 6.02×10^{23} molecules of CO_2

Percent composition

- What is the mass composition of C in CO_2?
  - Not just a calculation of one mole of C per 3 moles of atoms in one mole of CO_2...must calculate the percent by weight (mass) of the 12g carbon per mole in the 44g per mole CO_2
  - 5-10-5 fertilizer is a good practical example
    - 5%N, 10%P_2O_5, 5%K_2O
    - Empirical formula?

Percent composition (cont'd)

Molecular formula of butane	C_4H_{10}
Mass of C in 1 mol C_4H_{10}	$4 \text{ mol C} \times 12.011 \text{ g C/mol C} = 48.044 \text{ g C}$
Mass of H in 1 mol C_4H_{10}	$10 \text{ mol H} \times 1.0079 \text{ g H/mol H} = 10.079 \text{ g H}$
Molar mass of C_4H_{10}	$48.044 \text{ g C} + 10.079 \text{ g H} = 58.123 \text{ g/mol } C_4H_{10}$
Mass percent C in C_4H_{10}	$\frac{48.044 \text{ g C}}{58.123 \text{ g } C_4H_{10}} \times 100\% = 82.66\% \text{ C}$
Mass percent H in C_4H_{10}	$\frac{10.079 \text{ g H}}{58.123 \text{ g } C_4H_{10}} \times 100\% = 17.34\% \text{ H}$

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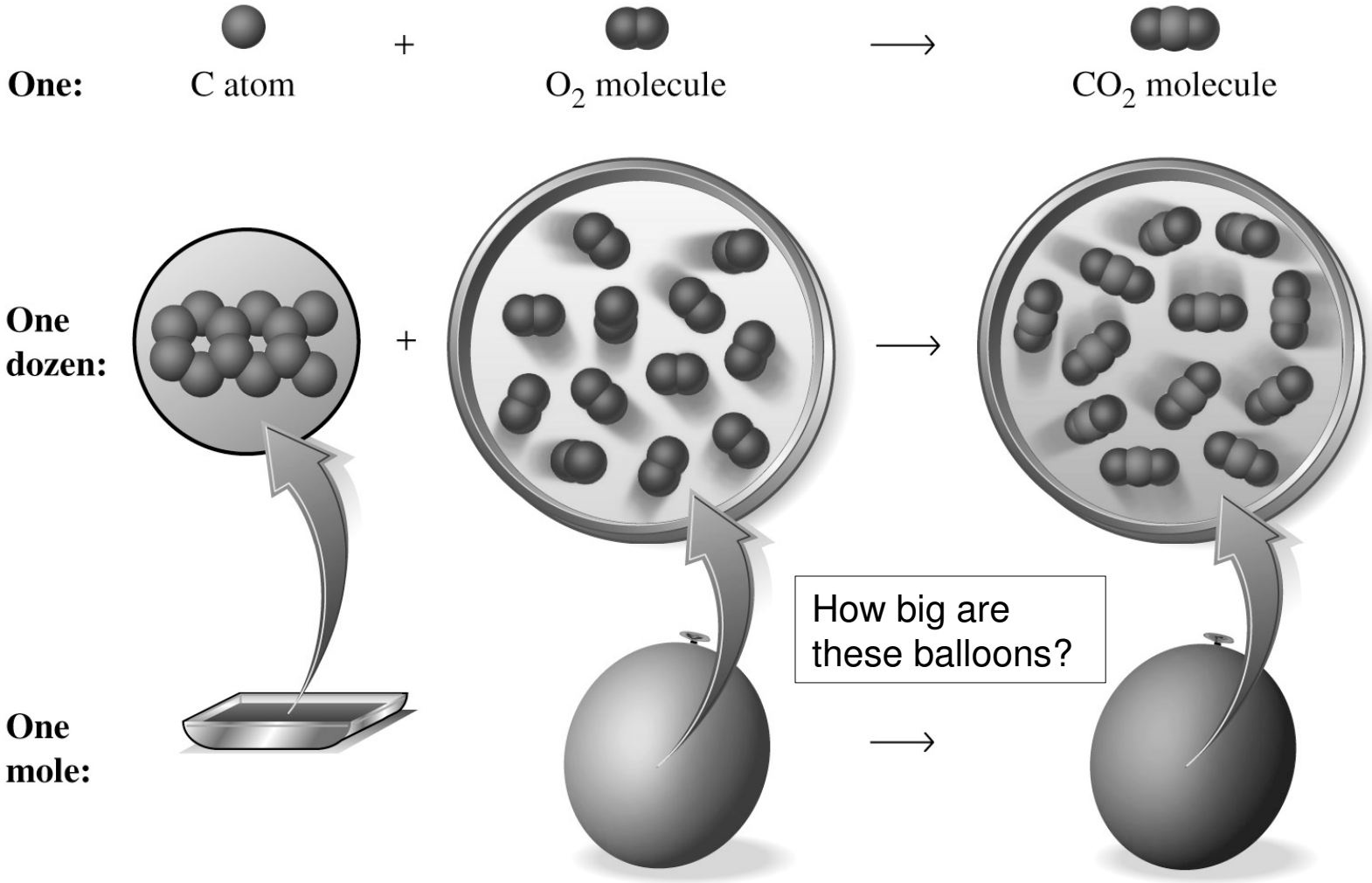
Percent composition (cont'd)

- Given the mass percents, you should be able to determine the empirical formula...given the molecular mass, you should be able to determine the chemical formula
- UNITS, UNITS, UNITS
- Determined experimentally by a technique called ELEMENTAL ANALYSIS

Equations

- REACTANTS on the L, PRODUCTS on the R
- $CO + 2H_2 \rightarrow CH_3OH$
  - Stoichiometry- QUANTITATIVE relationship between (or measurement of) substances.
  - In the reaction of CO with H_2 to produce CH_3OH, one MOLECULE of carbon monoxide is *stoichiometrically equivalent* to two MOLECULES of hydrogen and one MOLECULE of methanol...This molecule ratio of 1:2:1 applies to MOLES as well, and allows us to generate conversion factors which are extremely useful.
    - How many g of H2 are required to react with 28g CO?
    - (28g CO) (1 mol CO/28g CO) **(2 mol H_2/1 mol CO)** (2g H_2/mol H_2)

Equations- development/meaning



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Equations

- Sometimes, there is additional info present

Elevated temperature

$$NH_4Cl(s) \xrightarrow{\Delta} NH_3(g) + HCl(g)$$

Actual temperature at which reaction is carried out

$$HCOOH(g) \xrightarrow{160\ ^\circ C} CO_2(g) + H_2(g)$$

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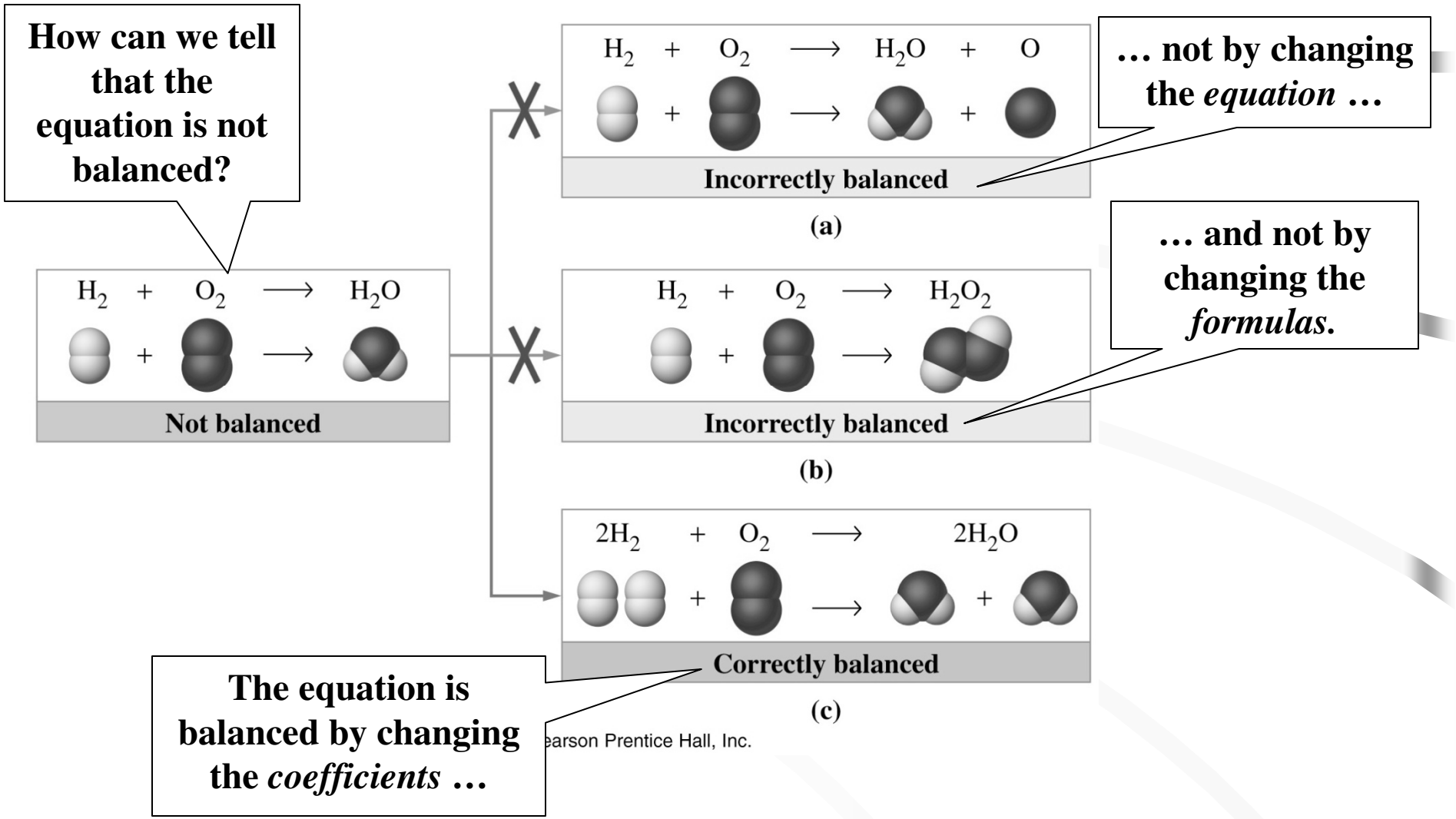
Balancing equations illustrated



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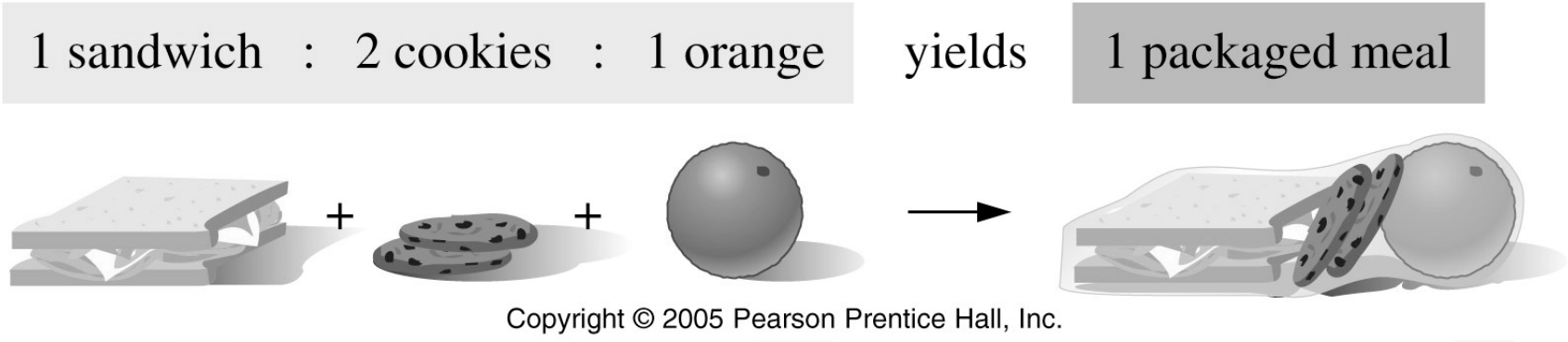
Guidelines for balancing chemical equations

- If an element is present in just one compound on each side of the equation, try balancing that element first.
- Balance any reactants or products that exist as the free element last.
- In some reactions, certain groupings of atoms (such as polyatomic ions) remain unchanged. In such cases, treat these groupings as a unit.
- At times, an equation can be balanced by first using a fractional coefficient(s). The fraction is then cleared by multiplying each coefficient by a common factor.
- Try starting with the heaviest element…
- Trial and error... Do it until it works!

Yield

- If one reactant runs out before another, it is the LIMITING REACTANT or LIMITING REAGENT



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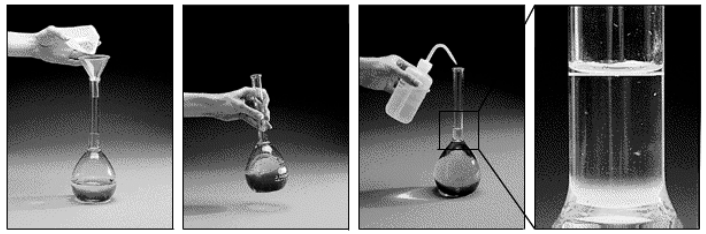
- May not be the one present in the lowest mass!!!
- Reactions do not always produce 100% of the product potential or THEORETICAL YIELD

Solutions

- A SOLUTE is dissolved in a SOLVENT to form a SOLUTION
- The solvent is usually present in greater amount than the solute
- DILUTE and CONCENTRATED are terms which refer to the relative CONCENTRATION of the solution- how much solute is dissolved per unit of solvent



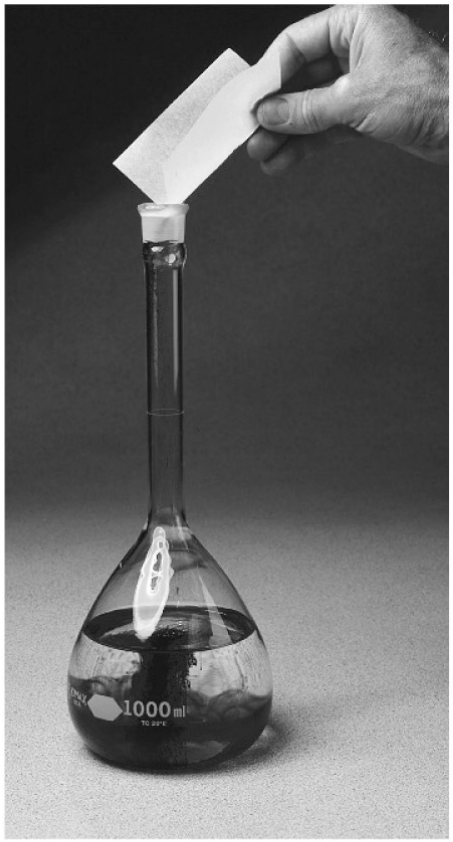
Solutions (cont'd)

- MOLARITY or MOLAR CONCENTRATION is the amount of SOLUTE in moles per LITER of SOLUTION
- We will rarely deal with MOLALITY, moles of solute per KILOGRAM of solvent
- Dilution does not change the amount of solute, but DOES change concentration
- $M_1V_1 = M_2V_2$
- Given the concentration of a reactant in solution, there is simply one more conversion (M to mol) involved in stoichiometric calculations

Solutions in the lab

- TC vs. TD

(a)



(b)

(c)

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Dilution of solutions

- ***Dilution*** is the process of preparing a more dilute solution by adding solvent to a more concentrated one.
- Addition of solvent does not change the amount of ***solute*** in a solution but does change the solution ***concentration***.
- It is very common to prepare a concentrated *stock solution* of a solute, then dilute it to other concentrations as needed.

Visualizing the dilution of a solution

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