Worksheet for Quiz 7 (and Exam 3)

Italicized parts **are optional; I recommend skipping them.**

- Here is a way to understand the calculation of molar mass: If you imagine "ripping apart" 1 mole of C_5H_{12} into atoms, you'll have 5 moles of C + 12 moles of H, so "molar mass" is (5 mol C)(12 g/mol) + (12 mol H)(1 g/mol) = 72 g/mol, with 60 g of C + 12 g of H = 72 g C_5H_{12}
- An **amount** can be described as number, mass, or volume. Dr I wants you to be able to think logically about amounts by mentally visualizing relative amounts and using analogies with everyday objects that are lightweight and heavyweight. If you have 1000 tennis balls and 1000 bowling balls (same number of each) which has larger mass? And if you have 9000 g of tennis balls and 9000 g of bowling balls (same mass) do you see why there is a larger number of tennis balls? You can use similar logic for atoms & molecules, IF you develop a clear idea of which atoms are relatively light and heavy, and think clearly about the implications.

1a. For example, consider H_2 (2 g/mol) and O_2 (32 g/mol). If you have the same number of each (like 3.27 mol of H_2 and 3.27 mol of O_2) which will have a larger mass, and by what ratio-factor? (By what number do you multiply "mass of H_2" to get "mass of O_2"? Or vice versa, by what factor do you need to multiply "mass of O_2" to get "mass of H_2"?)

1b. If you have equal mass of each (such as 4.87 g H_2 , 4.87 g O_2), which sample has a larger number of atoms, and by what multiplicative ratio-factor? {1a-1b answers are below}

note: You can do 1a & 1b with intuitive visualizing-logic, or with mathematical-logic by actually doing the math and developing intuitive math-logic by asking, "does dividing by a larger number make the result smaller (compared with dividing by a small number) or larger?" And does dividing by a small number make the result relatively larger (yes, it does) or smaller (no, it doesn't). Compare 64/32 (=2) and 64/4 (=16) and 64/.4 (=160); the result is literally larger when you divide by a number < 1, as when dividing 64 by .4 (which is < 1) gives 160, which is larger than 64.

- You can use similar "intuitive logic" for amounts of molecules in chemical reactions. For example, let's look at this reaction: <u>1</u> C_5H_{12} + <u>8</u> O_2 --> <u>5</u> CO_2 + <u>6</u> H_2O. We can think of this rxn at the level of molecules, or scaled-up by a factor of a million, or a mole, or by any other number; "million" is a word that means a large number (1,000,000 = 1×10^6) and "mole" is a word that means a much larger number (6.02×10^{23}). If we "scale up" a reaction by any number-factor, the AMOUNTS change but RATIOS remain the same. The reaction ratios (**1**-to-8-to-**5**-to-6) are the same whether 1 molecule of C_5H_{12} produces 5 molecules of CO_2 or if 1 mole of C_5H_{12} produces 5 moles of CO_2 . This idea of "RATIOS remaining the same when AMOUNTS are scaled-up" is a key to thinking about chemical reactions, and mastering chemistry calculations.

- *Or mass can be scaled-up from grams to kilograms, pounds, or tons, with conversion factors: metric (1000 g = 1 kg), non-metric (454 g = 1 lb, 2000 lbs = 1 ton). If 2.35 g is scaled-up by x454 (making its mass 454 times larger) the math is (235 g)(<u>x454</u>)(1 lb / 454 g) so it's now 235 lb. "1 lb / 454 g" is a conversion factor (describing the same thing in two ways, so it = 1 because top & bottom are equal) but the scaling-factor (<u>x454</u>) actually makes the amount larger.*

<u>1a</u>. O_2 has more mass, by factor of 32/2 = 16, H_2 has less (1/16).
<u>1b</u>. There is more H_2 by a factor of 32/2 = 16, as in Problem 4.

- These equations describe the same amounts in two ways,

<u>1 mole</u> C_5H_{12} + <u>8 moles</u> O_2 --> <u>5 moles</u> CO_2 + <u>6 moles</u> H_2O
<u>72 g</u> C_5H_{12} + <u>256 g</u> O_2 --> <u>220 g</u> CO_2 + <u>108 g</u> H_2O

because "8 moles O_2" is the same as "256 g O_2" (they're just different ways to describe the same amount of O_2) and so on.

<u>72 g</u> C_5H_{12} + <u>256 g</u> O_2 --> <u>220 g</u> CO_2 + <u>108 g</u> H_2O
<u>72 lbs</u> C_5H_{12} + <u>256 lbs</u> O_2 --> <u>220 lbs</u> CO_2 + <u>108 lbs</u> H_2O
<u>72 tons</u> C_5H_{12} + <u>256 tons</u> O_2 --> <u>220 tons</u> CO_2 + <u>108 tons</u> H_2O

Compared with the first two equations (1 mole... and 72 g...) the final two equations (72 lbs... and 72 tons...) are scaled-up by 454 and 454x2000) so they have different AMOUNTS, and "8 mole O_2 = 256 lbs O_2" is false; but all 4 equations have the same RATIOS: "mass CO_2 produced / mass C_5H_{12} reacting" = (220 g / 72 g) = (220 lbs / 72 lbs) = (220 tons / 72 tons) = 3.06, and their "constant ratio" is useful for doing problems like this:

2a. In a complete combustion of 43.8 grams C_5H_{12} , what mass of CO_2 (in g) is produced? **2b**. In the complete combustion of 43.8 tons C_5H_{12} , what weight of CO_2 (in tons) is produced? **<u>2a</u>**. (43.8 g C_5H_{12})(1 mol C_5H_{12} / 72 g C_5H_{12})(5 mol CO_2 / 1 mol C_5H_{12})(44 g CO_2 / 1 mol CO_2) = 134 g CO_2. **<u>2b</u>**. An easy solution is to "scale up" the reaction from grams to tons, so if 43.8 g C_5H_{12} produces 134 g CO_2 , then 43.8 tons C_5H_{12} will produce 134 tons CO_2 . *Or, if you convert from tons into grams, work the problem (as in 2a) with g, and then convert from grams back to tons, you'll see 2000 & 454 each used twice, once on fraction-top and once on fraction-bottom, so the 2000's and 454's "cancel" and the only remaining numbers are those in the 2a solution: 43.8 (1/72) (5/1) (44/1).* **For more practice, do problems 6a-6b.**

3a. What weight of CO_2 (in pounds) is produced by complete combustion of 1 gallon of gasoline? (1 gallon = 3785 mL ; assume gasoline is pure octane; C_8H_{18} density = .70 g/mL) [answer is 18.0 lbs; a solution-setup is at end of worksheet]

***3b**. Solve 3a using info from Sceptical Chymist 3.24 (pg 126), "a clean-burning automobile engine will emit about 5 lb of C in the form of CO_2 for every gallon of gasoline it consumes."*
***<u>3b</u>**: If an engine emits "5 lb of **<u>C</u>** in the form of **CO_2**" it will emit more than 5 lbs of CO_2 by a factor of (44 g CO_2 /12 g C) which — because a mass-ratio **between** molecules (as in 2a) or **within** a molecule (here) is the same whether masses are in g or lbs — is also (44 lb CO_2 / 12 lb C), so (5 lbs C) (44 lb CO_2 / 12 lb C) = 18 lbs CO_2 emitted, same as in 3a.*

<u>Problem-Solving Tips</u>

Almost always, **if grams are "given"** you will convert this to moles by using moles/gram; and **if moles are "given"** you will convert this to grams by using grams/mole. For example, in #2a "g/mol" is used twice (flipped & as-is) and in-between you use the mole/mole reaction-ratio to convert from moles of what you are GIVEN into moles of what you are asked to FIND.

If you are asked to find an AMOUNT, you **must** begin with an AMOUNT, and then use conversion factors (= 1) to convert it into a different description of the same AMOUNT.

If you are asked to find a RATIO, either you can begin with a RATIO or (more commonly) use the "miles/hour strategy" as in this example: if you know that a sample of n-octane has mass = 265 g, and volume = 379 mL, to find its density in g/mL you divide the g by mL, (265 g / 379 mL) = .699 g/mL .

4. 64 g of oxygen gas is __ mol, 64 g hydrogen gas is __ mol. The key idea here is that "oxygen gas" means "the naturally occurring form of oxygen" which is diatomic O_2 not just O. Which 7 gases are diatomic? (He Ne,... are monotomic gas); memory - HAH (Hydrogen Air Halogens, 124), BrINClHOF.

5a. What is the mass of 234 mL n-C_8H_{18} ? (density = .70 g/mL)
5b. What is the volume of 164 g of n-C_8H_{18} ? **[mL ↔ g]**
5c. If 234 mL of n-C_8H_{18} is 164 g of it, what is its density?

6a. Write 4 equations, for incomplete combustion (to $CO+H_2O$) and complete combustion (CO_2+H_2O) for butane & butene.

6b. 43.8 g of butane produces ______ g of CO with incomplete combustion, and _____ g of CO_2 with complete combustion; 43.8 lb of butene produces _____ lb of CO with incomplete combustion, and ____ lb of CO_2 with complete combustion.

7. What is the name, formula, and molar mass of the alk<u>anes</u> with 1-8 carbons? the 7 smallest alk<u>enes</u> and alk<u>ynes</u> (how many C's do they have) with only one C=C or triple bond?

8a. Draw isomers for alk<u>anes</u> with 1-6 carbons & *(optional) 7-8.* The number of isomers for CH_4 and C_2H_6 and C_3H_8 is only 1; C_4H_{10} has 2 isomers, and C_5H_{12} has 3; C_6H_{14} has 5 isomers, with table-columns (2345678) giving hints for what they are (1 with longest chain of 6 Cs, 2 where longest chain is 5 Cs, and 2 with longest chain of 4 Cs); *if you want a challenge, C_7H_{16} has 9 isomers (1, 2, 5, and 1 for chains with lengths of 7, 6, 5, and 4); C_8H_{18} has 18 isomers (1, 3, 7, 6, 1 for chains with longest lengths of 8, 7, 6, 5, and 4 carbons),*
http://www.kentchemistry.com/links/organic/isomersofalkanes.htm

alkanes	#	longest chain	2	3	4	5	6	7	8
C_3H_8	1		0	1	-	-	-	-	-
C_4H_{10}	2		0	1	1	-	-	-	-
C_5H_{12}	3		0	0	2	1	-	-	-
C_6H_{14}	5		0	0	2	2	1	-	-
C_7H_{16}	9		0	0	1	5	2	1	-
C_8H_{18}	18		0	0	1	6	7	3	1

8b. Draw isomers for alk<u>enes</u> with 2-5 carbons & *(optional) 6-7.* C_2H_4 and C_3H_6 have 1 isomer, C_4H_8 has 3; C_5H_{10} has 5 (2 and 3 for C-chains with lengths of 5 and 4). With <u>cyclo</u>-isomers, C_3H_6 and C_4H_8 and C_5H_{10} have 1,2, and 4 more isomers, respectively.

alkenes	#	cyclo	2	3	4	5	6	7
C_3H_6	1	+1	0	1	-	-	-	-
C_4H_8	3	+2	0	1	2	-	-	-
C_5H_{10}	5	+4	0	0	0 3	2	-	-
C_6H_{12}	13	+7	0	0	1 2	3 4	3	-
C_7H_{16}	27	+11	0	0	1	1 2 2 2 5	5 6	3

• Chlorine: A <u>chlori**n**e atom</u> has 7 valence electrons, so it is a neutral free radical (because with an odd number it MUST have an unpaired electron) without an octet, and it's very reactive, as in its reaction that begins the ozone-depleting reaction cycle. / A <u>chlori**n**e molecule</u>, Cl_2, is neutral, has two octets, no unpaired electrons (has unshared non-bonding els); is stable by itself but can be split by visible light, often reacts with other chemicals. / A <u>chlori**d**e ion</u> has charge of -1, and 8 valence electrons (octet); usually it's chemically stable, unreactive with other chemicals.

In the Periodic Table, notice that Cl has two numbers: **17** (its **atomic number**) shows that every Cl has 17 protons; **35.45** (its **molar mass**) shows that 1 mole of "natural Cl" is 35.45 grams.

Chlorine has two main isotopes: 76% is ^{35}Cl (34.97 g/mole) with 18 neutrons, 24% is ^{37}Cl (36.97 g/mole) with 20 neutrons; a **weighted average** of this **naturally occurring mixture of isotopes** is 35.45 g/mol. Using math intuition for a **weighted** average, does it make sense that 35.45 is closer to 35 than 37?

There is no Cl-isotope with molar mass = 35.45, but 1 mole of "naturally occurring" Cl atoms will have mass of 35.45 g.
This skill may be useful elsewhere, but for 108-exams you won't need to calculate a weighted average: .76 (34.97) + .24 (36.97) = 35.45

• answers for assigned problems <u>in CiC</u>, p 146-7: **<u>40a</u>** (1 3 2 3), **<u>40b</u>** (2), **<u>40c</u>** (30); **<u>41c</u>** (6 vs 8); **<u>45</u>** ([73 mt CH_4][12 mt C / 16 CH_4] = 55 mt C); <u>and online</u> - **<u>1b</u>** (.43g $NaHCO_3$ -> .18g CO_2), **<u>3e</u>** (1600g , 1875 mL)

<u>ANSWERS for Problems — 4 , 7 , 6a-6b , 5a-5b-5c</u>:

<u>4</u>. 64 g (1/32) = 2 mole of O_2 , 64 g (1/2) = 32 mole of H_2 .
diatomics: Hydrogen (H_2), Air (N_2 O_2), Halogens (F_2 Cl_2 Br_2 I_2)

<u>7</u>. mother eats peanut butter (meth<u>ane</u> ethane propane butane), pentane hexane heptane octane; the number of C-and-H is C_nH_{2n+2} so it's CH_4 C_2H_6 C_3H_8 C_4H_{10} C_5H_{12} C_6H_{14} C_7H_{16} C_8H_{18} ;
molar masses: 16 30 44 58 72 86 100 114

alk<u>enes</u>: names are like alkanes but with "ane" replaced by "ene": ~~methene~~ eth<u>ene</u> propene butene pentene... ; if one C=C it loses 2 Hs; to see why, draw an alkane, then convert one C-C into C=C and (oops) two C's now have 5 bonds, so (because C wants 4 bonds) you must remove one H from each C, thus the loss of 2 H's; now convert an alkane into a cycloalkane, and you'll also see a loss of 2 H; for each, H's go from 2n+2 to 2n, and with C_nH_{2n} it's C_2H_4 C_3H_6 C_4H_8 C_5H_{10} C_6H_{12} C_7H_{14} C_8H_{16}
and molar masses are 28 42 56 70 84 98 112
names: ~~methene~~ eth<u>ene</u> propene butene pentene hexene ...

alk<u>ynes</u>: eth<u>yne</u> propyne etc; formula is C_nH_{2n-2} (losing two more Hs; why?) - C_2H_2 C_3H_4 C_4H_6 C_5H_8 C_6H_{10} C_7H_{12} C_8H_{14}
molar masses: 26 40 54 68 82 96 110

<u>6a</u>. butane incomplete: $2\ C_4H_{10} + 9\ O_2 \rightarrow 8\ CO + 10\ H_2O$
butane complete: $2\ C_4H_{10} + 13\ O_2 \rightarrow 8\ CO_2 + 10\ H_2O$
butene incomplete: $2\ C_4H_8 + 8\ O_2 \rightarrow 8\ CO + 8\ H_2O$
butene complete: $2\ C_4H_8 + 12\ O_2 \rightarrow 8\ CO_2 + 8\ H_2O$

note: Cutting coefficient-#s in half is ok if they represent moles (... + 4.5 mol O_2 ...) not molecules. *Compared with incomplete combustion for 1 mole of C_4H_{10} (or C_4H_8), why is 2 more moles O_2 required for complete combustion? Why is 1 mole less H_2O produced per mole of butene, compared with butane? Do these differences (a. 2 more moles O_2 , b. 1 less mole H_2) change if the hydrocarbon changes from C_4 to C_8 ? (a changes, b is same)*

<u>6b</u>. C_4H_{10} (84.6g CO, 133g CO_2);
C_4H_8 (87.6 lb CO, 138 lb CO_2)

<u>ENERGY BALANCES</u>

<u>5a</u>. 234 mL (.70 g / 1 mL) = 164 g
<u>5b</u>. 164 g (1 mL / .70 g) = 234 mL
<u>5c</u>. (134 g / 234 mL) = .701 g/mL

<u>3a</u>: (1 gal) (3785 mL/gal) (.70 g C_8H_{18} / mL C_8H_{18}) **(1 mol C_6H_{18} / 114 g C_8H_{18}) (8 mol CO_2 / 1 mol C_8H_{18}) (44 g CO_2 / 1 mol CO_2)** (1 lb / 454 g)

ENERGY BALANCES: changed by **enhanced** greenhouse effect? **<u>incoming E = outgoing E</u>** is needed for <u>steady state with constant temperature</u>; transient-**<u>radiation</u>** (100 = 6 + 25 + 46 + 23) and ultimate-**<u>radiation</u>** (100 = 6 + 25 + 60 + 9), **<u>atmosphere</u>** (23 + 37 = 60), **<u>earth</u>** (46 = 37 + 9).
Figure 3.2 is simplified, so it doesn't show some complex interactions; for example, "much of this heat is redirected and comes back..." (CiC, pg 103)
Sun's EM radiation (UV, visible, infrared) differs (re: transmission, reflection, absorption, emission) as explained in CiC, shown by yellow, blue, red.