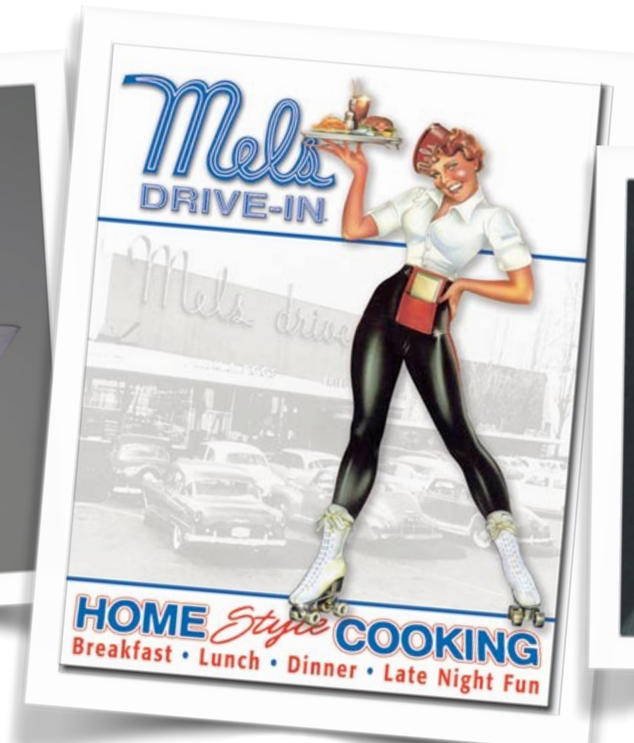
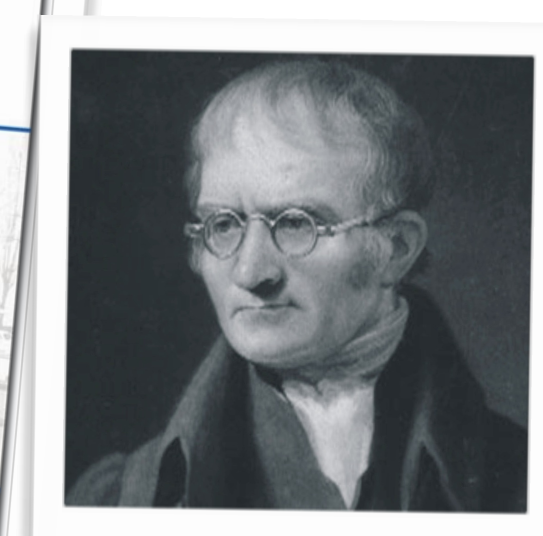
CHEM 100
Principles Of Chemistry





Chapter 5 - How Chemists Measure Atoms & Molecules

5.1 Weighing Objects to Count Objects

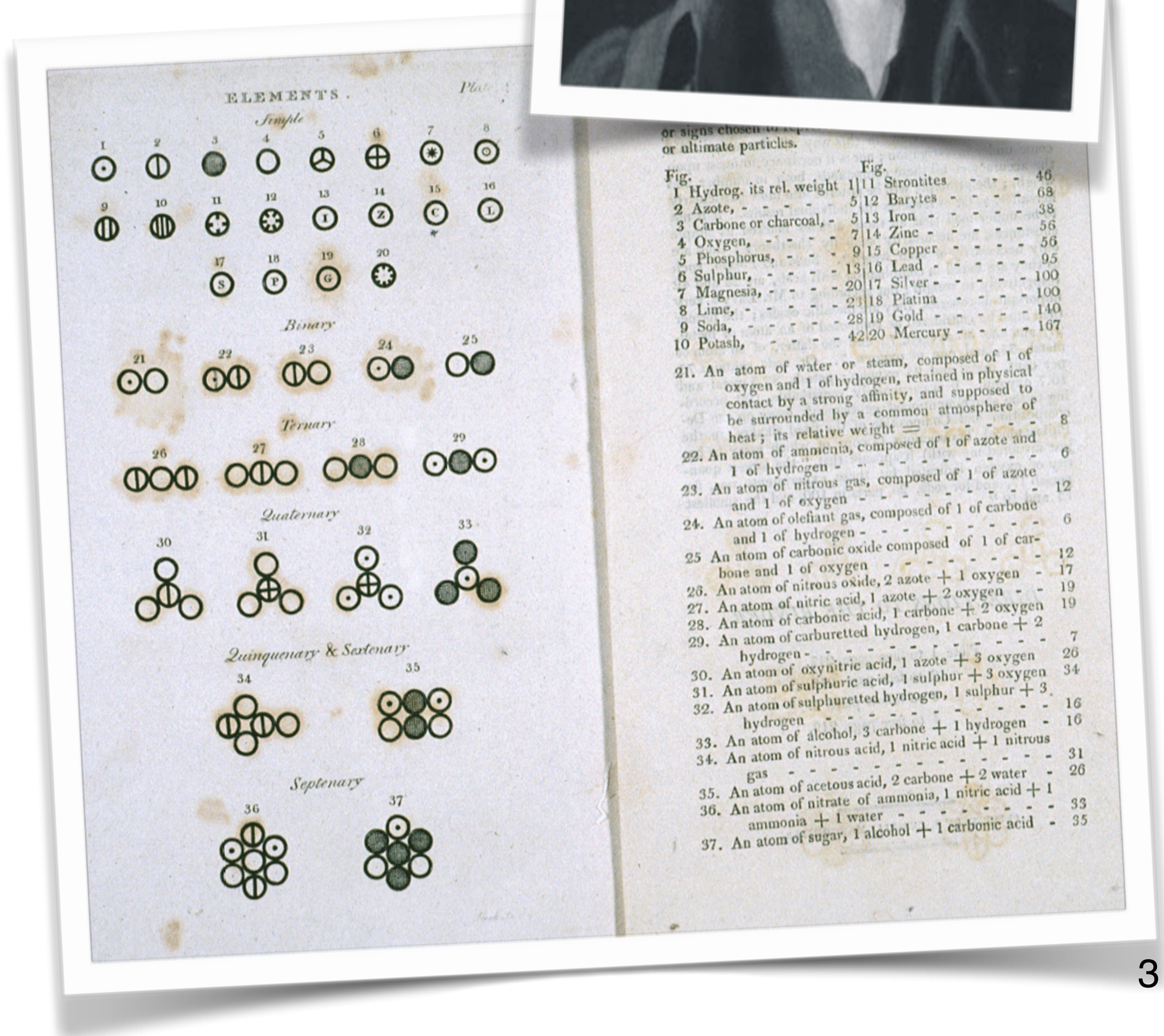
- When coin parking meters are emptied, the coins are not counted but weighed
- By knowing that a quarter weighs about 5.67 g, the number of quarters collected can be determined

$$\text{Number coins} = \text{Mass of coins (g)} \times \underbrace{\frac{1\,\text{coin}}{5.67\ \text{g}}}_{\text{Conversion factor}}$$

5.2 Weighing Invisible Objects

- The weighing method also works for objects too small to see, such as atoms
- But atoms weigh ~10^{-22} g!
- **John Dalton** came up with a relative scale by comparing the masses of the atoms to the lightest atom, hydrogen
  - – H has an **atomic weight** of 1

John Dalton
(1766-1844)



Weighing Invisible Objects

- The present system of atomic weights compares the mass of an atom with 1/12 mass of a C-12 atom
  - 1/12 mass of a C-12 atom is called the **atomic mass unit** (u)
  - One C-12 atom has a mass of exactly 12 u
  - 1 u = 1.6605×10^{-24} g
- Atomic weight A_r is

$$A_r = \frac{\text{Mass of 1 atom}}{1/12 \text{ mass of C} - 12 \text{ atom}}$$

Unitless

- Mass of a proton = 1.0073 u, neutron = 1.0087 u and electron = 0.00055 u
- Mass of a Au atom = 197.0 u

Calculating with Atomic Weight

Q The atomic weight of S is 32.07. What is the mass in g of one S atom?

A

$$A_r = \frac{\text{Mass of 1 S atom}}{\text{1/12 mass of C} - \text{12 atom}}$$

$$32.07 = \frac{\text{Mass of 1 S atom}}{1.6605\text{x}10^{-24}\ \text{g}}$$

$$\text{Mass of 1 S atom} = 32.07 \times 1.6605\text{x}10^{-24}\ \text{g}$$

$$= 5.325\text{x}10^{-23}\ \text{g}$$

$1\ u = 1.6605\text{x}10^{-24}\ g$

Calculating with Atomic Weight

Q How many C atoms are there in a 1-carat diamond (0.200 g) if the atomic weight of C is 12.01?

A Solution map: Atomic weight → Mass 1 C atom → Number of C atoms

$$A_r = \frac{\text{Mass of 1 C atom}}{\text{1/12 mass of C} - \text{12 atom}}$$

$$12.01 = \frac{\text{Mass of 1 C atom}}{1.6605\text{x}10^{-24}\ \text{g}}$$

$$\text{Mass of 1 C atom} = 12.01 \times 1.6605\text{x}10^{-24}\ \text{g}$$

$$= 1.994\text{x}10^{-23}\ \text{g}$$

$\boxed{1\ \text{u} = 1.6605\text{x}10^{-24}\ \text{g}}$

Calculating with Atomic Weight

A Solution map: Atomic weight → Mass 1 C atom → Number of C atoms

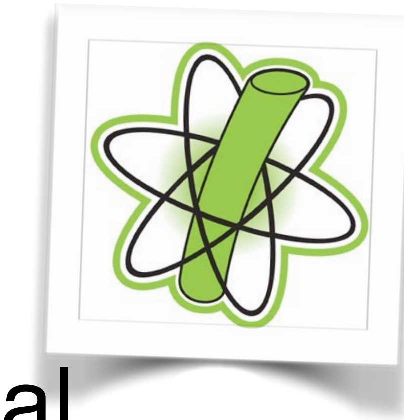
$$\text{Number C atoms} = \text{Mass of C atoms (g)} \times \frac{1\,\text{C atom}}{1.994\text{x}10^{-23}\ \text{g}}$$

Conversion factor

$$= 0.200\ \text{g} \times \frac{1\,\text{C atom}}{1.994\text{x}10^{-23}\ \text{g}}$$

$$= 1.00\text{x}10^{22}\ \text{C atoms}$$

Isotopes



- But, not all atoms of each element are identical
- This results from different numbers of neutrons
- Atoms with the same number of protons and electrons but different numbers of neutrons are called **isotopes**
  - <u>All</u> Cl atoms have 17 protons and 17 electrons
  - Some Cl atoms have 18 neutrons (^{35}Cl or Cl-35) and some Cl atoms have 20 neutrons (^{37}Cl or Cl-37)
  - 75.76% of natural Cl atoms have an atomic weight of 34.969 (Cl-35) and 24.24% of natural Cl atoms have an atomic weight of 36.966 (Cl-37)
- So which atomic weight do we use in calculations?

Isotopes

- Since almost all calculations will involve a large number of atoms, we can use a **weighted average** atomic weight
  - A weighted average takes into account the fractional abundance of each isotope and its atomic weight

$$\text{Average atomic weight Cl} =$$

$$\underbrace{\left(\underbrace{\frac{75.76}{100}}_{\text{abundance}} \times \underbrace{34.969}_{\text{atomic weight}}\right)}_{^{35}\text{Cl isotope}} + \underbrace{\left(\underbrace{\frac{24.24}{100}}_{\text{abundance}} \times \underbrace{36.966}_{\text{atomic weight}}\right)}_{^{37}\text{Cl isotope}} = 35.45$$

Average atomic weight

	1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1	1 H 1.008																	2 He 4.002
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 15.99	9 F 19.00	10 Ne 20.18
3	11 Na 22.99	12 Mg 24.30											13 Al 26.98	14 Si 28.08	15 P 30.97	16 S 32.07	17 Cl 35.45	18 Ar 39.95
4	19 K 40.00	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.8	53 I 126.9	54 Xe 131.3
6	55 Cs 132.9	56 Ba 137.2		72 Hf 178.5	73 Ta 180.9	74 W 183.8	75 Re 186.2	76 Os 190.2	77 Ir 192.2	78 Pt 195.1	79 Au 197.0	80 Hg 200.6	81 Tl 204.4	82 Pb 207.2	83 Bi 209.0	84 Po 209.0	85 At 201.0	86 Rn 222.0
7	87 Fr 223.0	88 Ra 226.0		104 Rf (261)	105 Db (262)	106 Sg (266)	107 Bh (264)	108 Hs (277)	109 Mt (268)									

6	57 La 138.9	58 Ce 140.1	59 Pr 140.9	60 Nd 144.2	61 Pm (145)	62 Sm 150.4	63 Eu 152.0	64 Gd 157.2	65 Tb 158.9	66 Dy 162.5	67 Ho 164.9	68 Er 167.3	69 Tm 168.9	70 Yb 173.0	71 Lu 175.0
7	89 Ac (227)	90 Th 232.0	91 Pa 231.0	92 U 238.0	93 Np 237.0	94 Pu (244)	95 Am (243)	96 Cm (247)	97 Bk (247)	98 Cf (251)	99 Es (254)	100 Fm (257)	101 Md (260)	102 No (259)	103 Lr (262)

5.3 The Mole

- Since individual atoms weigh so little, any conventional sample will contain huge numbers of atoms
- To make counting large numbers easier, chemists have developed a counting unit called the **mole** (mol)
  - The mole is based on atomic weight
  - It is defined as the number of atoms in exactly 12 g of C-12
- This number is the **Avogadro constant** or Avogadro's number ($\mathbf{N_A}$)

$$1 \text{ mol} = 6.022\text{x}10^{23}$$

Amedeo Avogadro (1776-1856)

The Mole and Avogadro's Constant

- Think of the mole as a counting unit like dozen
  - 1 dozen = 12
- If a market buys 60 dozen eggs daily we can calculate how many eggs this is

$$60\ \text{dozen} \times \frac{12\ \text{eggs}}{1\ \text{dozen}} = 720\ \text{eggs}$$

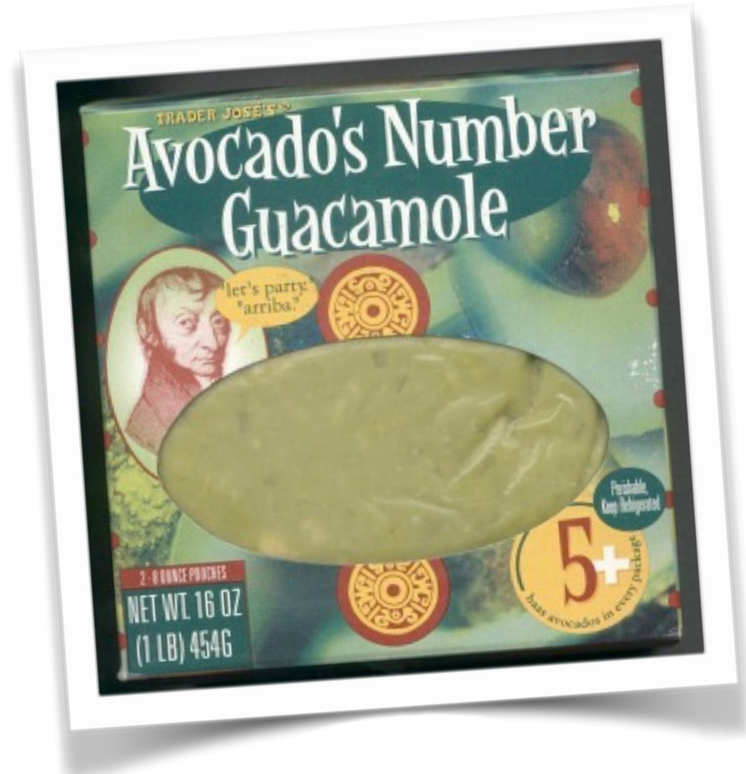
- The mole is simply a 'larger dozen'

The Mole and Avogadro's Constant

- Avogadro's constant can be used as a conversion factor

$$1\,\text{mol} = 6.022\text{x}10^{23}$$

A conversion factor



- 1 mole of <u>anything</u> contains $6.022\text{x}10^{23}$ <u>anythings</u>

Q How many individual grains are there in 0.55 moles of rice grains?

A
$$0.55\,\text{mols} \times \frac{6.022\text{x}10^{23}\ \text{grains}}{1\,\text{mol}} = 3.3\text{x}10^{23}\ \text{grains}$$

One Mole Quantities

- There are about 1 mole of stars in the visible universe
- About 1 mole of grapefruits would have the same volume as Earth
- There are about 1 mole of human cells on Earth
  - 6 billion people, each with about 100 trillion (10^{14}) cells
- 1 mole of sulfur atoms weighs about 32 g
- 18 mL of water contains about 1 mole of H_2O molecules

Moles $\overset{N_A}{\leftrightarrow}$ Particles

Atoms, ions, molecules...

Q How many atoms are there in 0.033 moles of Au?

A Solution map: Moles → Particles

$$0.033\,\text{moles} \times \frac{6.022\text{x}10^{23}\ \text{atoms}}{1\,\text{mole}} = 2.0\text{x}10^{22}\ \text{atoms}$$

Q How many moles of molecules are there in 4 million molecules of alcohol?

A Solution map: Particles → moles

$$4\text{x}10^{6}\ \text{molecules} \times \frac{1\,\text{mole}}{6.022\text{x}10^{23}\ \text{molecules}} = 6.64\text{x}10^{-18}\ \text{moles}$$

Molar Mass

- Being able to convert between number of particles and moles is not very useful by itself
- We need a conversion factor between moles and mass
- This conversion factor is the **molar mass**
  - Units are g/mol
- The molar mass is the **mass in grams of one mole of a substance**
  - We already know one conversion factor - 12 g of ${}^{12}_{6}C$ = 1 mol
- For elements, these numbers appear on the periodic table

Molar mass in g/mol

	1A	2A	3B	4B	5B	6B	7B	8B	8B	8B	1B	2B	3A	4A	5A	6A	7A	8A
1	1 H 1.008																	2 He 4.002
2	3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 15.99	9 F 19.00	10 Ne 20.18
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4	19 K 40.00	20 Ca 40.08	21 Sc 44.96	22 Ti 47.88	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.69	29 Cu 63.55	30 Zn 65.39	31 Ga 69.72	32 Ge 72.61	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
5	37 Rb 85.47	38 Sr 87.62	39 Y 88.91	40 Zr 91.22	41 Nb 92.91	42 Mo 95.94	43 Tc (99)	44 Ru 101.1	45 Rh 102.9	46 Pd 106.4	47 Ag 107.9	48 Cd 112.4	49 In 114.8	50 Sn 118.7	51 Sb 121.8	52 Te 127.8	53 I 126.9	54 Xe 131.3
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Moles $\xrightarrow{\text{Molar Mass}}$ Mass

4
Be
9.01

Atomic number

Molar mass

1 Be atom weighs 9.01 u
1 mol of Be weighs 9.01 g
The molar mass is 9.01 g/mol
1 mol Be = 9.01 g

- We can use the molar mass as a conversion factor between mols and mass

Q What is the mass of 0.420 moles of Fe?

A Solution map: Moles → mass

26
Fe
55.85

$$0.420\ \text{moles} \times \frac{55.85\ \text{g}}{1\ \text{mole}} = 23.5\ \text{g}$$

Mass $\xrightarrow{\text{Molar Mass}}$ Moles

16
S
32.07

- We can also do the reverse process

Q How many moles are in 16.52 g of S?

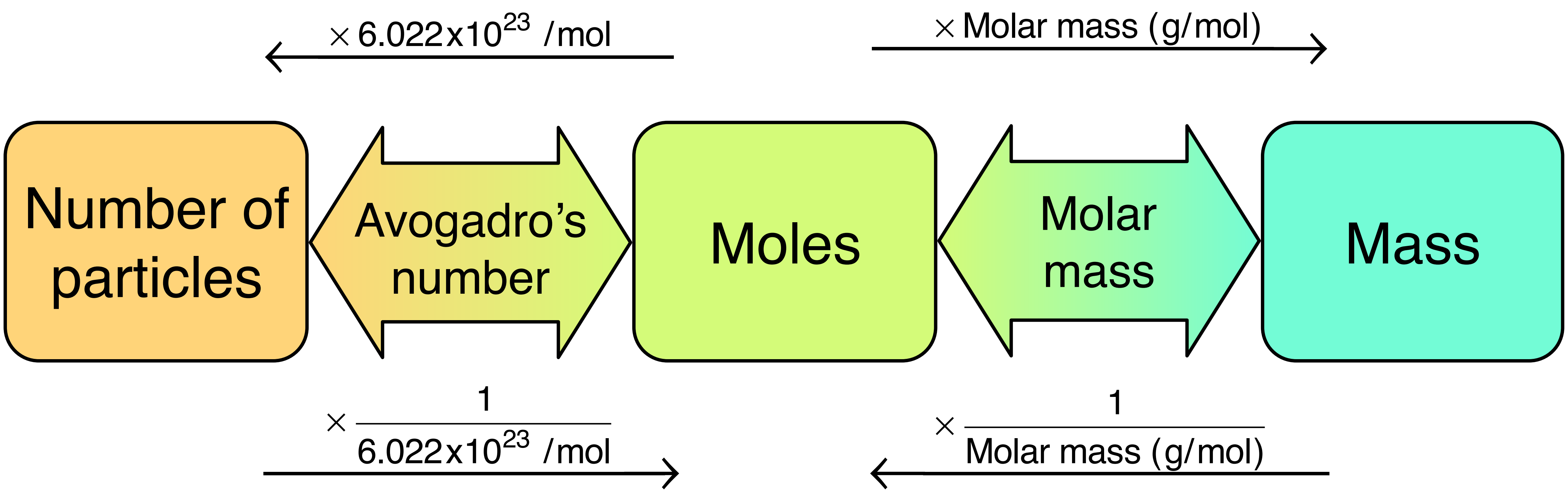
A 1 mol of S has a mass of 32.07 g so we must have less than 1 mol

Solution map: Mass → moles

$$16.52\ \text{g} \times \frac{1\,\text{mole}}{32.07\ \text{g}} = 0.5151\,\text{mole}$$

Converting Particles $\overset{N_A}{\leftrightarrow}$ Moles $\overset{\text{Molar Mass}}{\leftrightarrow}$ Mass

- We have developed two conversion factors and can convert between any combination of number of particles, moles and mass
- Calculating <u>number of moles is central!</u>



Particles $\xleftrightarrow{N_A}$ Moles $\xleftrightarrow{\text{Molar Mass}}$ Mass

9
F
19.00

Q What is the mass of $3.20\text{x}10^{12}$ F atoms?

A This requires two conversions

– Note there is no conversion factor for particles to mass in one step

Solution map: Particles → moles → mass

$$3.20\text{x}10^{12}\ \text{atoms} \times \underbrace{\frac{1\,\text{mole}}{6.022\text{x}10^{23}\ \text{atoms}}}_{\text{Avogadro's number}} \times \underbrace{\frac{19.00\ \text{g}}{1\,\text{mole}}}_{\text{Molar mass}} = 1.01\text{x}10^{-10}\ \text{g}$$

- **These type of conversions are very frequent and useful in chemistry!**

Mass $\xleftrightarrow{\text{Molar Mass}}$ Moles $\xleftrightarrow{N_A}$ Particles

30
Zn
65.39

Q How many atoms are there in 2.04 g of Zn atoms?

A This requires two conversions

- Note there is no conversion factor for mass to particles in one step

Solution map: Mass → moles → particles

$$2.04\text{ g} \times \underbrace{\frac{1\text{ mole}}{65.39\text{ g}}}_{\text{Molar mass}} \times \underbrace{\frac{6.022\text{x}10^{23}\text{ atoms}}{1\text{ mole}}}_{\text{Avogadro's number}} = 1.88\text{x}10^{22}\text{ atoms}$$

5.4 Compound Molar Mass

6	8
C	O
12.01	15.99

- But the **molar mass of a compound is not on the periodic table**!
  - The **molar mass of a compound** is found by **adding the molar masses of its constituent elements** using its **chemical formula**

Q What is the molar mass of CO_2?
  - 1 mol CO_2 contains 1 mole C atoms and 2 moles O atoms

$$1\,\text{mole C} \times \frac{12.01\,\text{g}}{1\,\text{mole C}} = 12.01\,\text{g}$$

$$2\,\text{moles O} \times \frac{15.99\,\text{g}}{1\,\text{mole O}} = 31.98\,\text{g}$$

A The molar mass is (12.01 g + 31.98 g) = <u>43.99</u> g/mol

Test Yourself: Compound Molar Mass

1	6	8
H	C	O
1.008	12.01	15.99

Q What is the molar mass of sugar ($C_{12}H_{22}O_{11}$)?

A We must add together the molar masses of the atoms

$$12 \text{ moles C} \times \frac{12.01 \text{ g}}{1 \text{ mole C}} = 144.12 \text{ g}$$

$$22 \text{ moles H} \times \frac{1.008 \text{ g}}{1 \text{ mole H}} = 22.198 \text{ g}$$

$$11 \text{ moles O} \times \frac{15.99 \text{ g}}{1 \text{ mole O}} = 175.89 \text{ g}$$

The molar mass is (144.12 g + 22.198 g + 175.89 g) = <u>342.21</u> g/mol

Compound Moles ↔ Compound Mass

6
C
12.01

1
H
1.008

Q What is the mass of 0.664 moles CH_4 molecules?

A Solution map: Moles → mass

We need the molar mass of CH_4

Molar mass = (1 x 12.01 g/mol) + (4 x 1.008 g/mol) = 16.04 g/mol

$$0.664 \text{ moles} \times \underbrace{\frac{16.04 \text{ g}}{1 \text{ mole}}}_{\text{Molar mass}} = 10.7 \text{ g}$$

Compound Mass ↔ Compound Moles

Q How many moles of I_2 molecules is 0.500 kg of I_2?

A Solution map: Mass (kg) → mass (g) → moles

$$0.500\ \text{kg} \times \frac{10^3\ \text{g}}{1\ \text{kg}} = 500\ \text{g}$$

53
I
126.9

We need the molar mass of I_2

Molar mass = (2 x 126.9 g/mol) = 253.8 g/mol

$$500\ \text{g} \times \frac{1\ \text{mole}}{253.8\ \text{g}} = 1.97\ \text{moles}$$

Molar mass

5.5 Mass Percent Composition of Compounds

- We can now work out what percentage of the mass of a compound is due to each constituent (the **mass percent**)
- A sample of NaCl is 39% Na by mass
  - A 100 g sample of NaCl contains 39 g Na, 61 g Cl

$$\textbf{Mass \% X} = \frac{\textbf{Mass of X in sample}}{\textbf{Total mass of sample}} \times \textbf{100\%}$$

- The sum of all Mass % values is 100%

Mass Percent Composition

Q 3.92 g of Fe reacts to form 5.04 g of iron oxide. What is the mass % Fe in the iron oxide?

$$\text{Mass \% Fe} = \frac{\text{Mass of Fe in sample}}{\text{Total mass of sample}} \times 100\%$$

$$= \frac{3.92\text{ g}}{5.04\text{ g}} \times 100\% = 77.8\%$$

Mass Percent Composition

Q What mass of NaCl contains 2.40 g of Na given NaCl is 39% Na by mass?

$$\text{Mass \% Na} = \frac{\text{Mass of Na in sample}}{\text{Total mass of sample}} \times 100\%$$

$$\text{Total mass of sample} = \frac{\text{Mass of Na in sample}}{\text{Mass \% Na}} \times 100\%$$

$$= \frac{2.40\text{ g}}{39\%} \times 100\%$$

$$= 6.15\text{ g}$$

Enter ‘39’ and‘100’ in your calculator

Mass Percent Composition From Chemical Formulas

- It is possible to determine **the mass percent directly from a chemical formula** by assuming we have 1 mole of the compound

$$\textbf{Mass \% X} = \frac{\textbf{Mass of X in 1 mol sample}}{\textbf{Total mass of 1 mol sample}} \times \textbf{100\%}$$

Q What is the mass percent of Ca in $Ca_3(PO_4)_2$?

$$\text{Mass \% Ca} = \frac{\text{Mass of Ca in 1 mole sample}}{\text{Total mass of 1 mole sample}} \times 100\%$$

$$= \frac{3 \times 40.08\ \text{g/mol}}{310.18\ \text{g/mol}} \times 100\% = 38.76\%$$

5.6 Interpreting Chemical Reactions Quantitatively

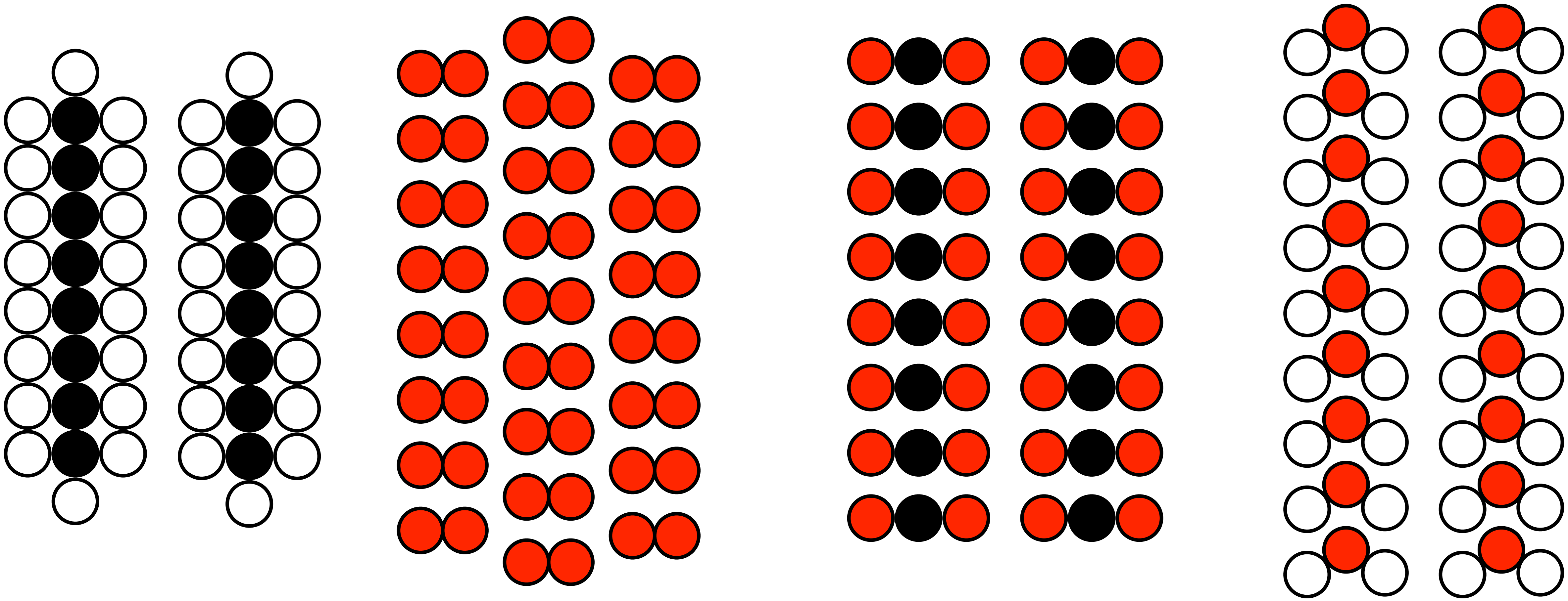
- Balanced chemical equations allow us to predict, in terms of molecules, the amounts of reactants required and products made
- For example

$$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(l)$$

- This reaction tells us <u>2</u> molecules of octane react with <u>25</u> molecules of oxygen to make <u>16</u> molecules of carbon dioxide and <u>18</u> molecules of water

Quantities In Chemical Quantities

$$2\ C_8H_{18}(l) \quad + \quad 25\ O_2(g) \quad \rightarrow \quad 16\ CO_2(g) \quad + \quad 18\ H_2O(l)$$



Quantities In Chemical Reactions

- The coefficients in our octane example can be multiplied by a constant factor and still be balanced

$$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(l)$$

x2 $$4\ C_8H_{18}(l) + 50\ O_2(g) \rightarrow 32\ CO_2(g) + 36\ H_2O(l)$$

x10 $$20\ C_8H_{18}(l) + 250\ O_2(g) \rightarrow 160\ CO_2(g) + 180\ H_2O(l)$$

- If we multiply by $6.022\text{x}10^{23}$ we get

$$2 \text{ mols } C_8H_{18}(l) + 25 \text{ mols } O_2(g) \rightarrow 16 \text{ mols } CO_2(g) + 18 \text{ mols } H_2O(l)$$

- <u>An equation can mean either molecules or moles</u>!

Moles In Chemical Quantities

$$2\ C_8H_{18}(l) + 25\ O_2(g) \rightarrow 16\ CO_2(g) + 18\ H_2O(l)$$

- This reaction tells us either...

  "**2 molecules** of octane react with **25 molecules** of oxygen to make **16 molecules** of carbon dioxide and **18 molecules** of water."
- Or...

  "**2 moles** of octane react with **25 moles** of oxygen to make **16 moles** of carbon dioxide and **18 moles** of water."
- Now we can do calculations with masses

Moles ↔ Moles In Chemical Reactions

- For example

$$2\ P(s) + 3\ Cl_2(g) \rightarrow 2\ PCl_3(l)$$

- The **stoichiometry** (balance) tells us

$$2 \text{ moles } P(s) = 3 \text{ moles } Cl_2(g) = 2 \text{ moles } PCl_3(l)$$

- We can write various **mole ratios** including

$$\frac{2 \text{ moles } P(s)}{3 \text{ moles } Cl_2(g)} \quad \text{or} \quad \frac{2 \text{ moles } P(s)}{2 \text{ moles } PCl_3(l)} \quad \text{or} \quad \frac{3 \text{ moles } Cl_2(g)}{2 \text{ moles } PCl_3(l)}$$

Each connects two different substances

There are 3 others we could write too?

Moles ↔ Moles In Chemical Reactions

Q How many moles of $H_2O(l)$ are produced from the combustion of 4.78 moles of $CH_4(g)$?

A Write the balanced chemical equation

$$CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(l)$$

Write the mole ratio connecting H_2O and CH_4

$$\frac{1\,\text{mole}\ CH_4}{2\,\text{mole}\ H_2O}$$

Or upside down version

Finally

$$4.78\,\text{moles}\ CH_4 \times \frac{2\,\text{mole}\ H_2O}{1\,\text{mole}\ CH_4} = 9.56\,\text{moles}\ H_2O$$

Test Yourself: Moles ↔ Moles In Chemical Reactions

Q How many moles of $N_2(g)$ are needed to completely react with 115 moles of $H_2(g)$ to make ammonia according to the following equation?

$$N_2(g) + 3\ H_2(g) \rightarrow 2\ NH_3(g)$$

A Write the mole ratio connecting N_2 and H_2

$$\frac{1\,\text{mole}\ N_2}{3\,\text{mole}\ H_2}$$

Or upside down version

Finally

$$115\ \text{moles}\ H_2 \times \frac{1\,\text{mole}\ N_2}{3\,\text{mole}\ H_2} = 38.3\ \text{moles}\ N_2$$

Mass ↔ Mass In Chemical Reactions

- We can also do problems involving mass if we remember that **number of moles is central**
- We <u>cannot</u> convert directly from mass to mass
  - The conversion factor for mass to moles is **molar mass** and moles to moles is **mole ratio**
- The strategy is think about what steps are possible and link them together
- Try not to memorize a sequence of steps for each type of calculation

Mass ↔ Mass In Chemical Reactions

Q How many kg of CO_2 are released when 1.00 kg of $CaCO_3$ undergoes decomposition?

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

We cannot go directly from mass to mass

We must convert mass to moles first and then moles to mass at the end

A Solution map: Mass $CaCO_3$ → moles $CaCO_3$ → moles CO_2 → mass CO_2

All quantities must be in g because molar mass is in g

Molar mass $CaCO_3$ = 100.06 g/mol

Molar mass CO_2 = 43.99 g/mol

Mass ↔ Mass In Chemical Reactions

Q How many kg of CO_2 are released when 1.00 kg of $CaCO_3$ undergoes decomposition?

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

A Solution map: Mass $CaCO_3$ → moles $CaCO_3$ → moles CO_2 → mass CO_2

$$1000\ \text{g}\ CaCO_3 \times \underbrace{\frac{1\ \text{mole}\ CaCO_3}{100.06\ \text{g}}}_{\text{Molar mass}} \times \underbrace{\frac{1\ \text{mole}\ CO_2}{1\ \text{mole}\ CaCO_3}}_{\text{Mole ratio}} \times \underbrace{\frac{43.99\ \text{g}}{1\ \text{mole}\ CO_2}}_{\text{Molar mass}}$$

$$= 439.6\ \text{g}\ CO_2 = 0.440\ \text{kg}$$

Test Yourself: Mass ↔ Mass In Chemical Reactions

Q How many kg of CaO are made when 1.00 kg of $CaCO_3$ undergoes decomposition?

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

A Solution map: Mass $CaCO_3$ → moles $CaCO_3$ → moles CaO → mass CaO

$$1000\text{ g } CaCO_3 \times \frac{1\text{ mole } CaCO_3}{100.06\text{ g}} \times \frac{1\text{ mole CaO}}{1\text{ mole } CaCO_3} \times \frac{56.07\text{ g}}{1\text{ mol CaO}}$$

$$= 560.4\text{ g CaO} = 0.560\text{ kg}$$

Notice that 1.00 kg of $CaCO_3$ makes 0.440 kg CO_2 plus 0.560 kg CaO?

Law of conservation of mass!

Test Yourself: Mass ↔ Mass In Chemical Reactions

Q How many grams of O_2 are consumed when 10.0 g of alcohol ($C_2H_6O(l)$) combusts?

$$C_2H_6O(l) + 3\ O_2(g) \rightarrow 2\ CO_2(g) + 3\ H_2O(l)$$

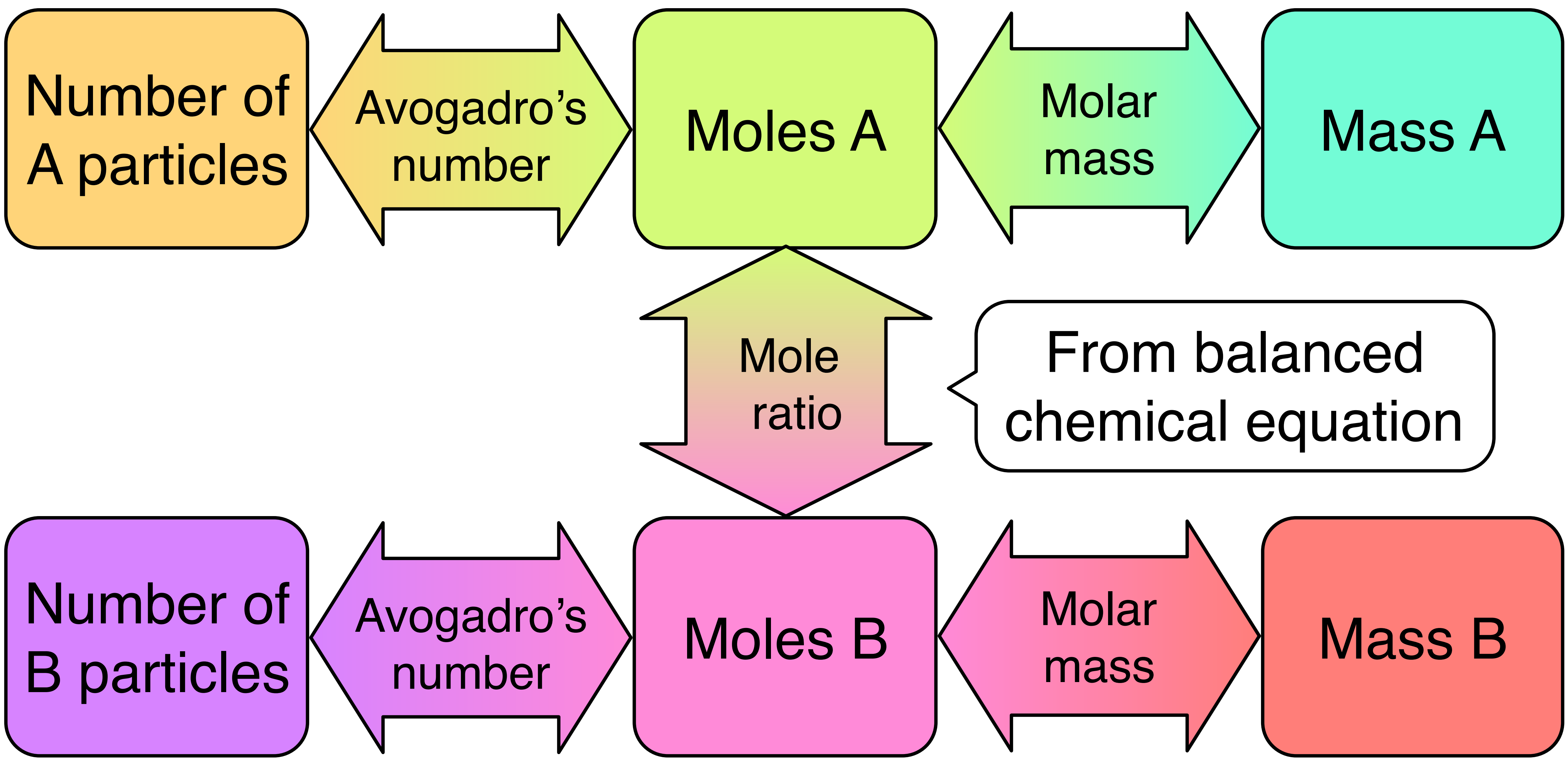
A Solution map: Mass alcohol → moles alcohol → moles oxygen → mass oxygen

$$10.0\ \text{g}\ C_2H_6O \times \underbrace{\frac{1\ \text{mole}\ C_2H_6O}{46.07\ \text{g}}}_{\text{Molar mass}} \times \underbrace{\frac{3\ \text{mole}\ O_2}{1\ \text{mole}\ C_2H_6O}}_{\text{Mole ratio}} \times \underbrace{\frac{31.98\ \text{g}}{1\ \text{mole}\ O_2}}_{\text{Molar mass}}$$

$$= 20.8\ \text{g}\ O_2$$

Converting Particles $\xleftrightarrow{N_A}$ Moles $\xleftrightarrow{\text{Molar Mass}}$ Mass

- Let’s redraw the map for particles, moles and mass



5.7 Limiting Reactants

- In some instances the reactants for a chemical reaction might be given in **stoichiometric amounts** (in the mole ratio indicated by the balanced chemical equation)

$$2\ H_2(g) + O_2(g) \rightarrow 2\ H_2O(l)$$

  - The equation indicates we need 2x as many moles of H_2 as O_2
- So stoichiometric amounts would be
  - 2 mols H_2 and 1 mol O_2
  - 1 mol H_2 and ½ mol O_2
  - 0.882 mols H_2 and 0.441 mols O_2

Always in the ratio 2 H_2 : 1 O_2

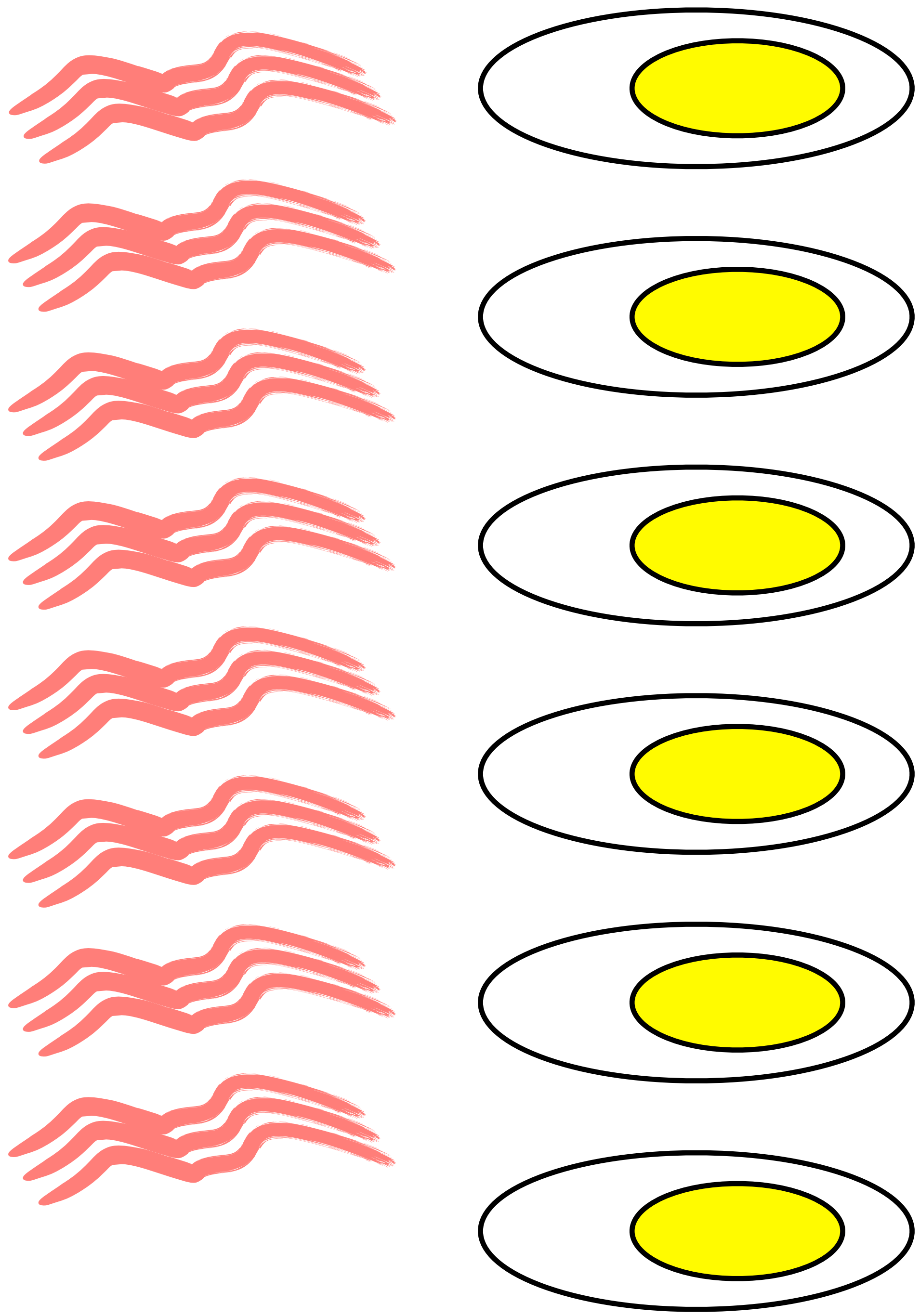
Limiting Reactants

- In other instances the reactants for a chemical reaction might <u>not</u> be given in stoichiometric amounts
- One of the reactants is used up first
- This is called the **limiting reactant** and the amount of product produced is called the **theoretical yield**
  - The limiting reactant is the reactant in shortest supply
  - The limiting reactant limits the amount of product that can be made
  - All limiting reactant is used up but some non-limiting reactant(s) remain

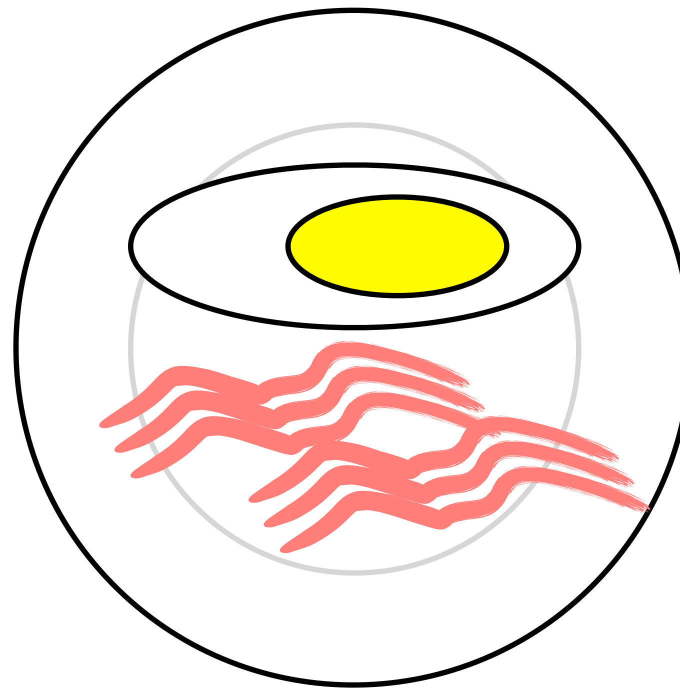
$$2\ S(g) + 3\ O_2(g) \rightarrow 2\ SO_3(g)$$

- What would happen if the reaction started with 2 moles of S and 1 mole of O_2?

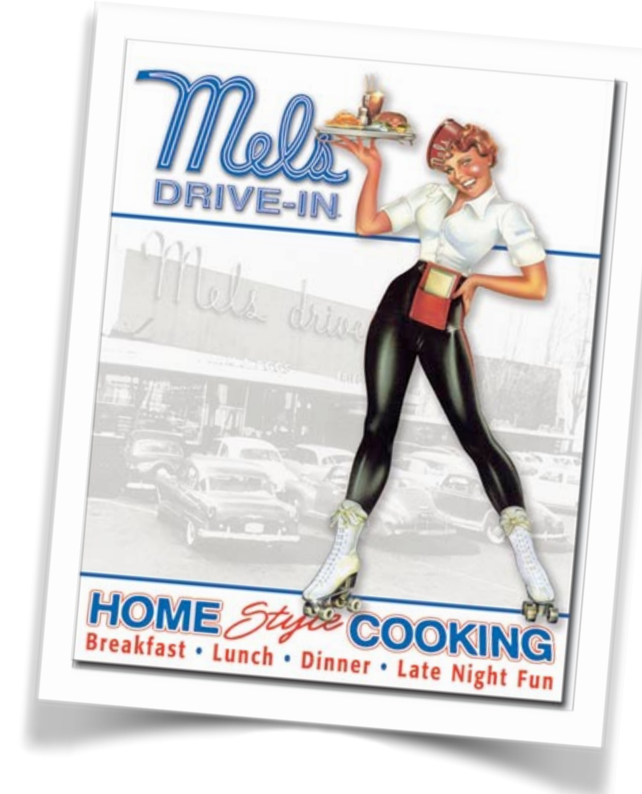
Limiting Ingredients



Bacon Eggs



= 1 breakfast



How many complete breakfasts can you serve?

Which is the limiting ingredient?

Limiting Reactants

$$2\ S(g) + 3\ O_2(g) \rightarrow 2\ SO_3(g)$$

- What would happen if the reaction started with 2 moles of S and 1 mole of O_2?
- We need more O_2 than we are provided with
  - We need 3 moles but we only have 1 mole
- The O_2 is the limiting reactant
  - It is in shortest supply
  - It is used up completely and some sulfur remains unreacted
- How do we find the limiting reactant in general?
- The limiting reactant is <u>the one that makes the least amount of product</u>

Limiting Reactants

Q 1.45 moles of SO_2 reacts with 0.92 moles of O_2. Which is the limiting reactant and how many moles of SO_3 will be made?

$$2\ SO_2(g) + O_2(g) \rightarrow 2\ SO_3(g)$$

A Find out which reactant makes the least amount of product

$$1.45 \text{ mols } SO_2 \times \frac{2 \text{ mols } SO_3}{2 \text{ mols } SO_2} = 1.45 \text{ mols } SO_3$$

Limiting reactant is SO_2

$$0.92 \text{ mols } O_2 \times \frac{2 \text{ mols } SO_3}{1 \text{ mol } O_2} = 1.84 \text{ mols } SO_3$$

Test Yourself: Limiting Reactants

Q 0.68 moles of C_3H_8 reacts with 3.50 moles of O_2. Which is the limiting reactant and how many moles of CO_2 will be made?

$$C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(l)$$

A Find out which reactant makes the least amount of product

$$0.68 \text{ mols } C_3H_8 \times \frac{3 \text{ mols } CO_2}{1 \text{ mol } C_3H_8} = 2.04 \text{ mols } CO_2$$

Limiting reactant is C_3H_8

$$3.50 \text{ mols } O_2 \times \frac{3 \text{ mols } CO_2}{5 \text{ mols } O_2} = 2.10 \text{ mols } CO_2$$

Test Yourself: Limiting Reactants

Q 0.44 moles of $Al(OH)_3$ reacts with 1.32 moles of HCl. Which is the limiting reactant and how many moles of H_2O will be made?

$$Al(OH)_3(s) + 3\ HCl(aq) \rightarrow AlCl_3(s) + 3\ H_2O(l)$$

A

$$0.44 \text{ mols } Al(OH)_3 \times \frac{3 \text{ mols } H_2O}{1 \text{ mol } Al(OH)_3} = 1.32 \text{ mols } H_2O$$

$$1.32 \text{ mols } HCl \times \frac{3 \text{ mols } H_2O}{3 \text{ mols } HCl} = 1.32 \text{ mols } H_2O$$

Limiting reactant?

A This is not a limiting reactant reaction (it is **stoichiometric**) and the amount of H_2O is 1.32 mols