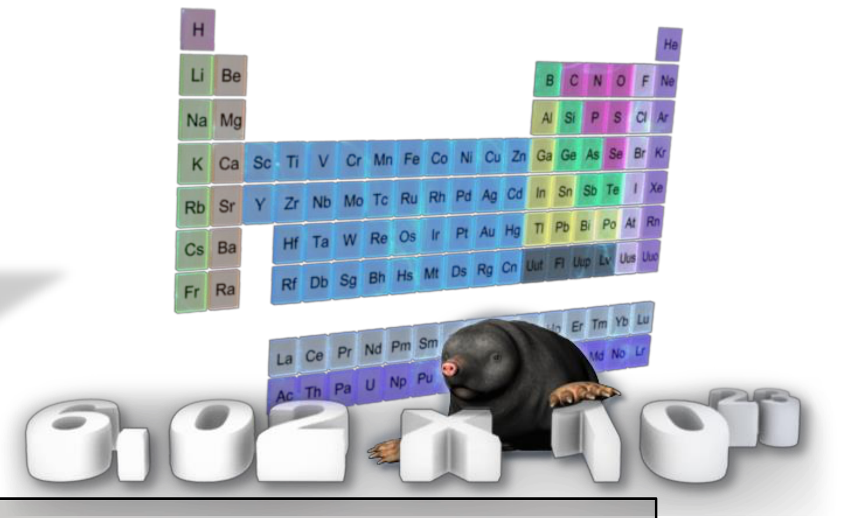
Topic 13

The Mole



Peer Instruction
Clicker Session 14

Topic 13 Learning Goals

As a student, I am able to:

1	recall and apply the basic rules of scientific notation, rounding, metric units and dimensional analysis
2	rearrange a basic algebraic expression to isolate any variable in the expression (i.e. mass = moles x molar mass)
3	balance a chemical equation and use the coefficients to predict the number of *atoms or molecules* produced or used in a chemical reaction
4	articulate that the atomic mass in the periodic table is the number of grams in a mole of the element. Alternatively, the atomic mass in the periodic table is the number of grams in an Avogadro's number of atoms
5	memorize and recall Avogadro's number: 6.023×10^{23} particles/mol and recognize that the number refers to a mole of objects (atoms, molecules, particles, ions)
6	compute the molar mass from the chemical formula
7	use the molar mass to convert between moles and masses for an arbitrary amount of a compound.
8	convert between numbers of particles, moles and grams
9	recognize that the stoichiometric coefficients in a balanced chemical equation can be interpreted as the number of atoms or molecules that combine or as the moles of atoms or molecules that combine.
10	I can use the stoichiometric coefficients as combining ratios to determine how many moles react and how many moles are formed.

Topic 13 Material

Molar Mass
Use the periodic table to determine the molar mass of any given compound from its chemical formula or from its name
Conversions (Mass ⇔ moles ⇔ particles)
Review Unit conversions from Topic 1
Use molar mass as conversion factor to convert between mass and moles
Use Avogadros number as a conversion factor to convert between moles and particles (molecules, atoms or ions)

T13Q1: Level 1 (L.G. 6)

What is the molar mass of the compound, $Cu_3(PO_4)_2$?

A. 110.5 g/mol
B. 237.6 g/mol
C. 316.6 g/mol
D. 349.6 g/mol
E. 380.6 g/mol

1A																	8A
1 **H** 1.008	**2A**											**3A**	**4A**	**5A**	**6A**	**7A**	2 He 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 23.00	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.70	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb**	38 **Sr**	39 **Y**	40 **Zr**	41 **Nb**	42 **Mo**	43 **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**	53 **I**	54 **Xe**

T13Q1: Solution

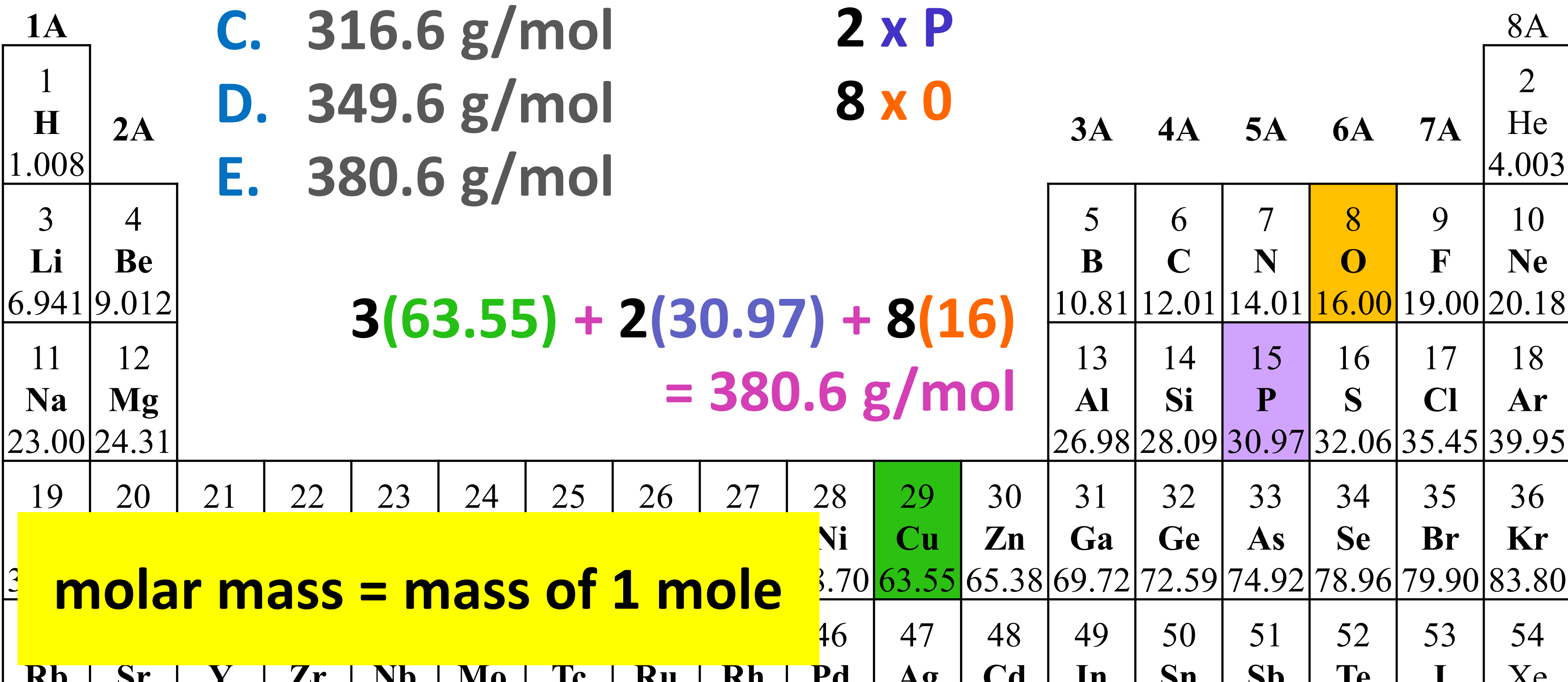
What is the molar mass of the compound, $Cu_3(PO_4)_2$?

A. 110.5 g/mol
B. 237.6 g/mol
C. 316.6 g/mol
D. 349.6 g/mol
E. 380.6 g/mol

$Cu_3(PO_4)_2$:
3 x Cu
2 x P
8 x O

$3(63.55) + 2(30.97) + 8(16)$
$= 380.6$ g/mol

molar mass = mass of 1 mole



T13Q2: Level 1 (L.G. 6)

The calcium sulfate used in gypsum is a hydrate (meaning that water is absorbed into the sulfate). The formula for gypsum is: $CaSO_4 \bullet 2H_2O$. How much would one mole of gypsum weight? In other words, what is its molar mass?

A. 172 g
B. 156 g
C. 147 g
D. 141 g
E. 136 g

1A	2A											3A	4A	5A	6A	7A	8A
1 **H** 1.008																	2 He 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 23.00	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.90	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.70	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb**	38 **Sr**	39 **Y**	40 **Zr**	41 **Nb**	42 **Mo**	43 **Tc**	44 **Ru**	45 **Rh**	46 **Pd**	47 **Ag**	48 **Cd**	49 **In**	50 **Sn**	51 **Sb**	52 **Te**	53 **I**	54 Xe

T13Q2: Solution

The calcium sulfate used in gypsum is a hydrate (meaning that water is absorbed into the sulfate). The formula for gypsum is: $CaSO_4 \bullet 2H_2O$. How much would one mole of gypsum weight? In other words, what is its molar mass?

A. 172 g

B. 156 g

C. 147 g

D. 141 g

E. 136 g

$CaSO_4 \bullet 2H_2O$:

1 x Ca

1 x S

6 x O

4 x H

$40.08 + 32.06 + 6(16.00) + 4(1.008) = 172$ g/mol

1A	2A											3A	4A	5A	6A	7A	8A
1 H 1.008																	2 He 4.003
3 Li 6.941	4 Be 9.012											5 B 10.81	6 C 12.01	7 N 14.01	8 O 16.00	9 F 19.00	10 Ne 20.18
11 Na 23.00	12 Mg 24.31											13 Al 26.98	14 Si 28.09	15 P 30.97	16 S 32.06	17 Cl 35.45	18 Ar 39.95
19 K 39.10	20 Ca 40.08	21 Sc 44.96	22 Ti 47.90	23 V 50.94	24 Cr 52.00	25 Mn 54.94	26 Fe 55.85	27 Co 58.93	28 Ni 58.70	29 Cu 63.55	30 Zn 65.38	31 Ga 69.72	32 Ge 72.59	33 As 74.92	34 Se 78.96	35 Br 79.90	36 Kr 83.80
37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54

T13Q3: Level 1 (L.G. 8)

How many moles of water are in 3.6 grams of water?

A. 2.6×10^{24} moles
B. 64.8 moles
C. 3.6 moles
D. 0.20 moles
E. 0.40 moles

1	8
H	O
1.008	16.00

T13Q3: Solution

How many moles of water are in 3.6 grams of water?

A. 2.6×10^{24} moles
B. 64.8 moles
C. 3.6 moles
D. 0.20 moles
E. 0.40 moles

1	8
H	O
1.008	16.00

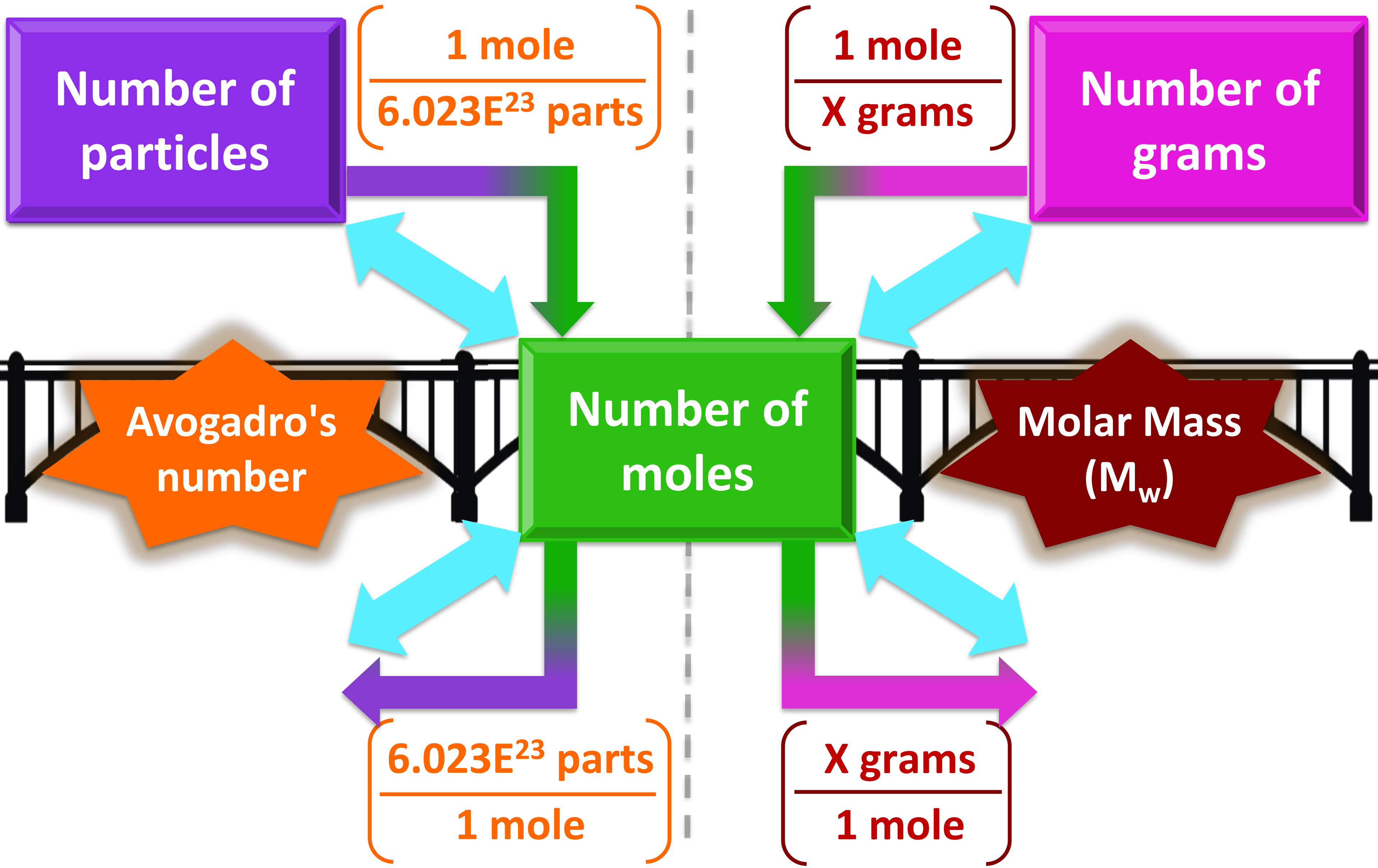
M_W of water:
2(1.008 g/mol) + (16.00 g/mol) = 18 g/mol

Grams H_2O → Moles H_2O

$$3.6\ \cancel{g\ H_2O} \times \frac{1\ mol\ H_2O}{18\ \cancel{g\ H_2O}} = 0.20\ \boxed{mol\ H_2O}$$

Your answer will have units of moles of H_2O

The MOLE bridge (A Summary)



T13Q4: Level 2 (L.G. 8)

How many grams of oxygen are there in 6.2 g of Li_3PO_4?

A. **0.054 grams**
B. **0.21 grams**
C. **3.43 grams**
D. **6.86 grams**

3	8	15
Li	O	P
6.94	16.00	30.97

T13Q4: Solution

How many grams of oxygen are there in 6.2 g of Li_3PO_4?

A. 0.054 grams
B. 0.21 grams
C. $\boxed{\text{3.43 grams}}$
D. 6.86 grams

3	8	15
Li	O	P
6.94	16.00	30.97

$$1Li_3PO_4 \rightarrow 3Li + 1P + 4O$$

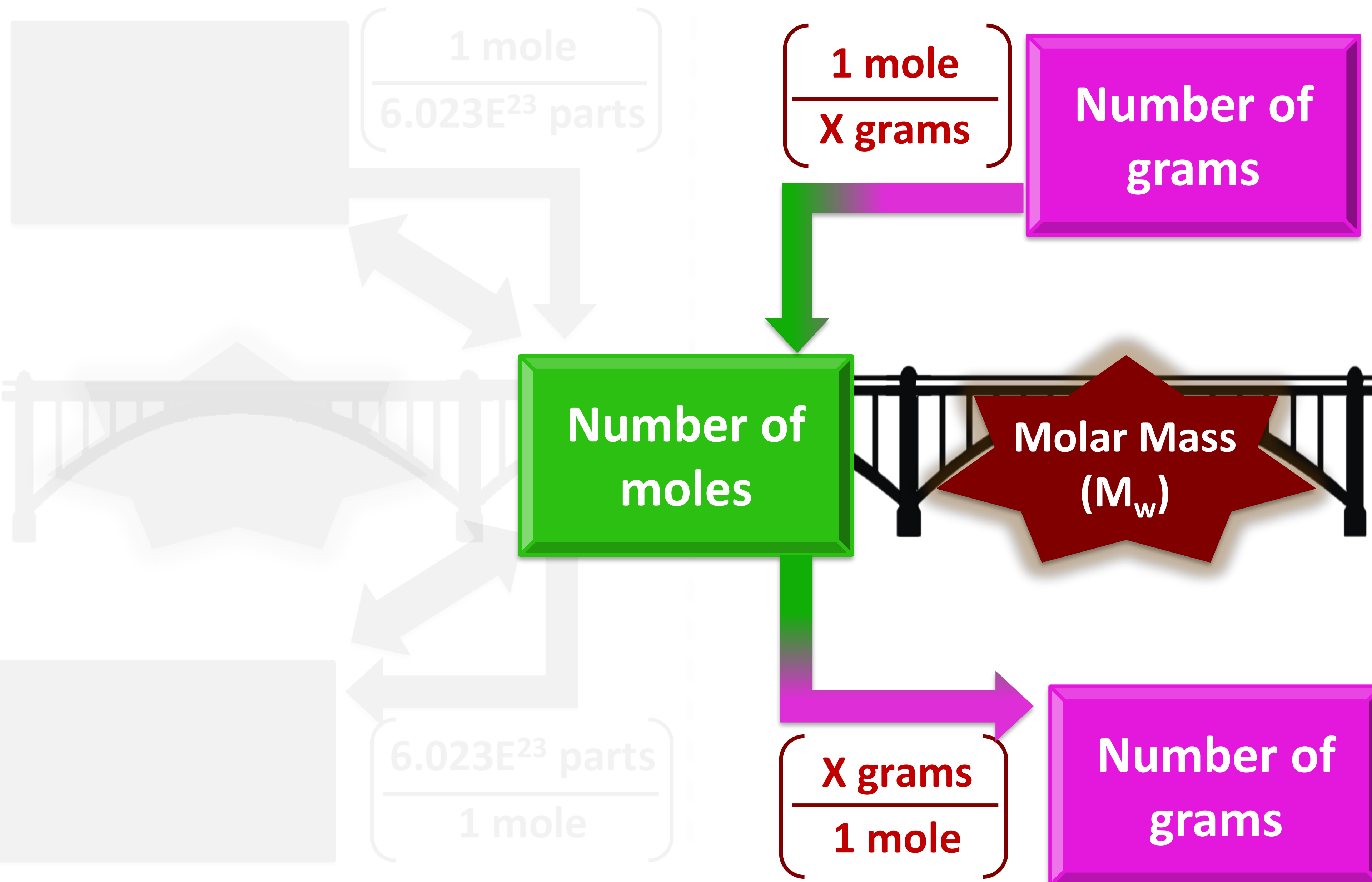
M_w of Li_3PO_4:
3(6.94 g/mol) + 30.97 g/mol + 4(16.00 g/mol) = 115.73 g/mol

Grams molecules → Moles molecules → Moles O atoms → Grams O

$$6.2\ \cancel{g\ Li_3PO_4} \times \frac{1\ \cancel{mole\ Li_3PO_4}}{115.73\ \cancel{g\ Li_3PO_4}} \times \frac{4\ \cancel{moles\ O}}{1\ \cancel{mole\ Li_3PO_4}} \times \frac{16\ \boxed{\text{grams O}}}{1\ \cancel{mole\ O}}$$

Your answer will have units of

The MOLE bridge (grams to grams)



T13Q5: Level 2 (L.G. 9)

How many molecules of water are in 4.1 grams of water?

A. **0.23 molecules**
B. **1.4 x 10^{23} molecules**
C. **2.5 x 10^{24} molecules**
D. **4.4 x 10^{25} molecules**

1	**8**
H	**O**
1.008	**16.00**

T13Q5: Solution

How many molecules of water are in 4.1 grams of water?

A. 0.23 molecules

B. $\boxed{1.4 \times 10^{23} \text{ molecules}}$

C. 2.5×10^{24} molecules

D. 4.4×10^{25} molecules

1	8
H	O
1.008	16.00

M_w of water:

$2(1.008 \text{ g/mol}) + (16.00 \text{ g/mol}) = 18 \text{ g/mol}$

Grams molecules → Moles molecules → Particles (molecules)

$$4.1 \text{ g } \cancel{H_2O} \times \frac{1 \text{ } \cancel{\text{mole}} \text{ } H_2O}{18 \text{ g } \cancel{H_2O}} \times \frac{6.022 \times 10^{23} \boxed{\text{molecules } H_2O}}{1 \text{ } \cancel{\text{mole}} \text{ } H_2O}$$

Your answer will have units of

T13Q6: Level 2 (L.G. 5)

How many fluorine molecules are there in a 38.00 g sample of fluorine gas?

9
F
19.000

A. **2.289 x 10^{25} molecules**
B. **6.023 x 10^{23} molecules**
C. **1.205 x 10^{24} molecules**
D. **2.553 x 10^{24} molecules**

T13Q6: Solution

How many fluorine molecules are there in a 38.00 g sample of fluorine gas?

9
F
19.000

A. 2.289×10^{25} molecules

B. $\boxed{6.023 \times 10^{23} \text{ molecules}}$

C. 1.205×10^{24} molecules

D. 2.553×10^{24} molecules

M_w of fluorine (F_2):
2(19g/mol) = 38 g/mol

Grams molecules → Moles molecules → Particles (molecules)

$$38\ \cancel{g\ F_2} \times \frac{1\ \cancel{mole}\ F_2}{38\ \cancel{g\ F_2}} \times \frac{6.023 \times 10^{23}\ \text{molecules}\ F_2}{1\ \cancel{mole}\ F_2}$$

T13Q7: Level 2 (L.G. 5)

How many fluorine atoms are there in a 38.00 g sample of fluorine gas?

9
F
19.000

- **A.** **2.289 x 10^{25} atoms**
- **B.** **6.023 x 10^{23} atoms**
- **C.** **1.205 x 10^{24} atoms**
- **D.** **2.553 x 10^{24} atoms**

T13Q7: Solution

How many fluorine atoms are there in a 38.00 g sample of fluorine gas?

9
F
19.000

A. 2.289 x 10^{25} atoms

B. 6.023 x 10^{23} atoms

C. 1.205 x 10^{24} atoms

D. 2.553 x 10^{24} atoms

$F_2 \rightarrow 2F$

M_w of fluorine (F_2):
2(19g/mol) = 38 g/mol

Grams molecules → Moles molecules → Moles (atoms) → Particles (atoms)

Your answer will have units of

$$38\,\cancel{g\,F_2} \times \frac{1\,\cancel{mole\,F_2}}{38\,\cancel{g\,F_2}} \times \frac{2\,\cancel{moles\,F\,atoms}}{1\,\cancel{mole\,F_2}} \times \frac{6.023 \times 10^{23}\,\boxed{atoms\,F}}{1\,\cancel{mole\,F\,atoms}}$$

T13Q8: Level 2 (L.G. 8)

How many moles of sodium atoms are there in 6.3 grams of sodium carbonate?

6	8	11
C	O	Na
12.01	16.00	23.00

A. 0.06 moles
B. 0.12 moles
C. 7.2 x 10^{22} moles
D. 3.6 x 10^{22} moles

T13Q8: Solution

How many moles of sodium atoms are there in 6.3 grams of sodium carbonate?

Na_2CO_3

A. 0.06 moles

B. $\boxed{\text{0.12 moles}}$

C. 7.2×10^{22} moles

D. 3.6×10^{22} moles

6	8	11
C	O	Na
12.01	16.00	23.00

$$1Na_2CO_3 \rightarrow 2Na + 1C + 3O$$

M_W of Na_2CO_3:

2(23 g/mol) + (12.01 g/mol) + 3(16.00 g/mol)

= 106 g/mol

Grams molecules → Moles molecules → Moles Na atoms

$$6.3\text{ g }\cancel{Na_2CO_3} \times \frac{1\cancel{\text{ mol }Na_2CO_3}}{106\text{ g }\cancel{Na_2CO_3}} \times \frac{\boxed{2\text{ mol Na}}}{1\cancel{\text{ mol }Na_2CO_3}}$$

Your answer will have units of moles of Na

T13Q9: Level 3 (L.G. 8)

How many moles of ions are there in a sample that is 10 g of magnesium phosphate, $Mg_3(PO_4)_2$?

8	**12**	**15**
O	**Mg**	**P**
16.00	**24.31**	**30.97**

A. **5.0 moles**
B. **0.49 moles**
C. **0.19 moles**
D. **0.038 moles**

T13Q9: Solution

How many moles of ions are there in a sample that is 10 g of magnesium phosphate, $Mg_3(PO_4)_2$?

3 Mg^{2+} & 2 PO_4^{3-}

5 ions per 1 molecule

8	12	15
O	Mg	P
16.00	24.31	30.97

A. 5.0 moles
B. 0.49 moles
C. $\boxed{\text{0.19 moles}}$
D. 0.038 moles

M_w of magnesium phosphate:

3(24.31) + 2(30.97) + 8(16.00) = 263 g/mol

Grams molecules → Moles molecules → Moles ions

$$10\ \cancel{g}\ Mg_3(PO_4)_2 \times \frac{1\ \cancel{mole}\ Mg_3(PO_4)_2}{263\ \cancel{g}\ Mg_3(PO_4)_2} \times \frac{5\ \boxed{\text{moles ions}}}{1\ \cancel{mole}\ Mg_3(PO_4)_2}$$

Your answer will have units of

T13Q10: Level 2 (L.G. 9)

How many C atoms are there in a sample of C_3H_8 that contains 6.59 x 10^{26} H atoms?

1	6
H	C
1.008	12.01

- **A.** 1.98 x 10^{27} C atoms
- **B.** 2.47 x 10^{26} C atoms
- **C.** 4.94 x 10^{26} C atoms
- **D.** 3.17 x 10^{24} C atoms

T13Q10: Solution

How many C atoms are there in a sample of C_3H_8 that contains 6.59×10^{26} H atoms?

1	6
H	C
1.008	12.01

A. 1.98×10^{27} C atoms

B. $\boxed{2.47 \times 10^{26}}$ C atoms

C. 4.94×10^{26} C atoms

D. 3.17×10^{24} C atoms

$$C_3H_8 \rightarrow 3C + 8H$$

Particles H atoms → Moles H → Moles C → Particles C atoms

Your answer will have units of **atoms C**

$$6.59 \times 10^{26}\ \cancel{H} \times \frac{1\ \cancel{mole\ H}}{6.022 \times 10^{23}\ \cancel{H}} \times \frac{3\ \cancel{mole\ C}}{8\ \cancel{mole\ H}} \times \frac{6.022 \times 10^{23}\ \boxed{atoms\ C}}{1\ \cancel{mole\ C}}$$

T13Q10: Solution Alternate

How many C atoms are there in a sample of C_3H_8 that contains 6.59×10^{26} H atoms?

1	6
H	C
1.008	12.01

A. 1.98×10^{27} C atoms
B. $\boxed{2.47 \times 10^{26} \text{ C atoms}}$
C. 4.94×10^{26} C atoms
D. 3.17×10^{24} C atoms

$$C_3H_8 \rightarrow 3C + 8H$$

Do you need Avogadro's number in this calculation?

NOPE, can go directly from
H atoms → C atoms
mole ratio = atom ratio

$$6.59 \times 10^{26}\ \cancel{H} \times \cancel{\frac{1\ \text{mole H}}{\boxed{6.022 \times 10^{23}\ H}}} \times \frac{3\ \cancel{\text{mole}}\ C}{8\ \cancel{\text{mole}}\ H} \times \cancel{\frac{\boxed{6.022 \times 10^{23}}\ \text{atoms C}}{1\ \text{mole C}}}$$

T13Q11: Level 2 (L.G. 9)

How many oxygen atoms are found in a 33 g sample of manganese(II) sulfite?

A. 1.44×10^{23} O atoms
B. 3.94×10^{23} O atoms
C. 4.44×10^{23} O atoms
D. 7.22×10^{23} O atoms

8	16	25
O	S	Mn
16.00	32.07	54.94

T13Q11: Solution

How many oxygen atoms are found in a 33 g sample of manganese(II) sulfite?

A. 1.44 x 10^{23} O atoms
B. 3.94 x 10^{23} O atoms
C. $\boxed{4.44 \times 10^{23} \text{ O atoms}}$
D. 7.22 x 10^{23} O atoms

Manganese(II) sulfite: $MnSO_3$
→ 1Mn + 1S + 3O

8	16	25
O	S	Mn
16.00	32.07	54.94

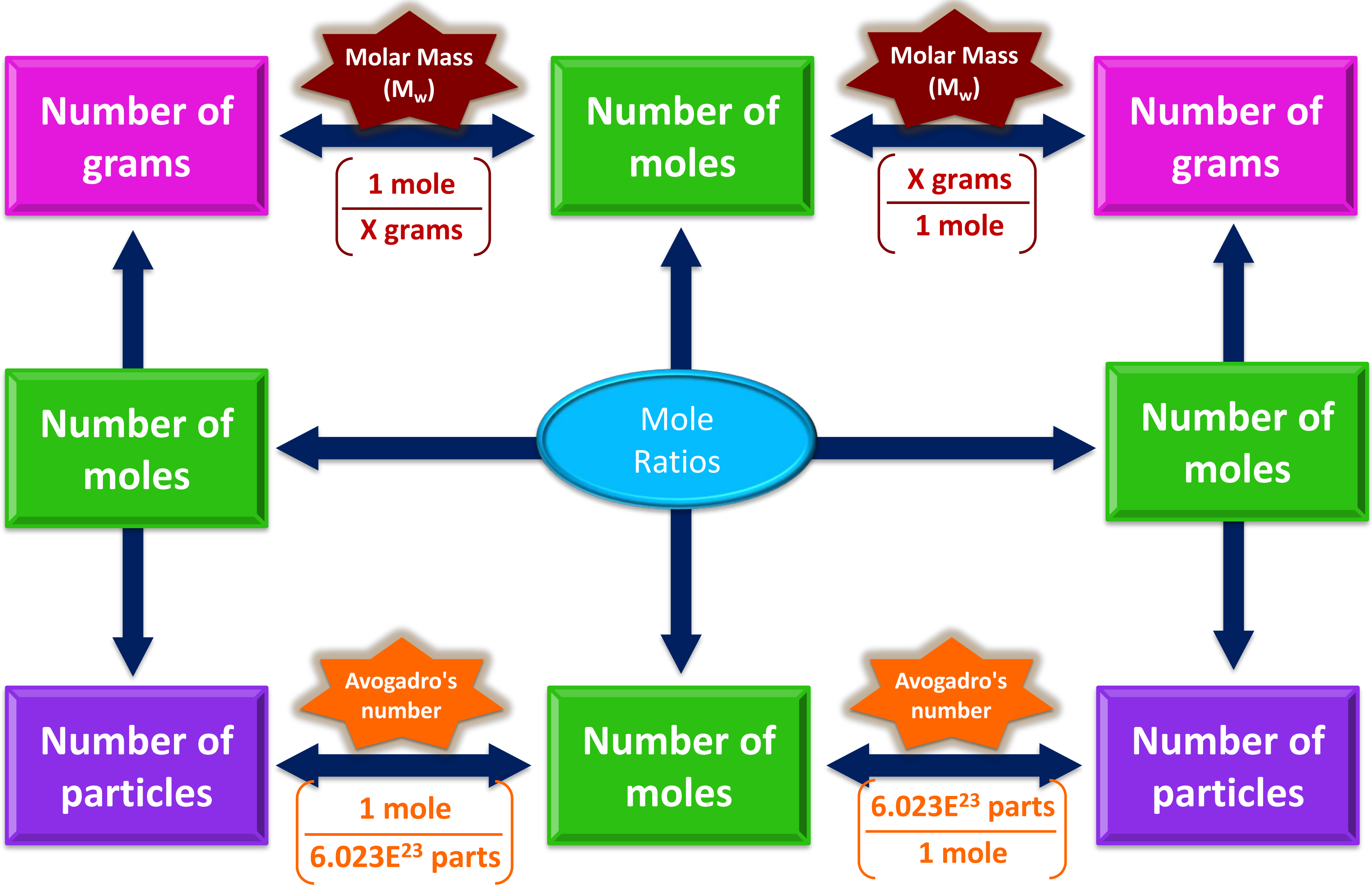
M_w of $MnSO_3$:
54.94 g/mol + 32.07 g/mol + 3(16.00 g/mol) = 135.0 g/mol

Grams molecules → Moles molecules → Moles O atoms → Particles (O atoms)

Your answer will have units of

$$33\,\cancel{g}\,MnSO_3 \times \frac{1\,\cancel{mole}\,MnSO_3}{135\,\cancel{g}\,MnSO_3} \times \frac{3\,\cancel{mole}\,O}{1\,\cancel{mole}\,MnSO_3} \times \frac{6.022 \times 10^{23}\,\boxed{\text{atoms O}}}{1\,\cancel{mole}\,O}$$

Mole conversions

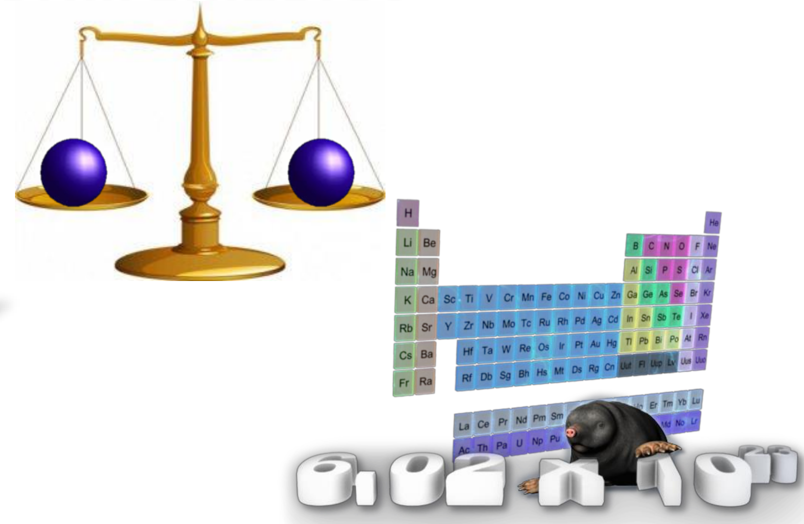


Topic 14

Stoichiometry

Stoicheion = Element
+ Metron = Measure

STOICHIOMETRY



Peer Instruction
Clicker Session 15

8 pt challenge

How many moles of sodium atoms are there in 4.4 grams of sodium carbonate?

6	8	11
C	O	Na
12.01	16.00	23.00

A. 2.5×10^{22} moles
B. 5.0×10^{22} moles
C. 0.04 moles
D. 0.08 moles
E. 0.12 moles

Q0: Solution

How many moles of sodium atoms are there in 4.4 grams of sodium carbonate?

Na_2CO_3

A. 2.5×10^{22} moles
B. 5.0×10^{22} moles
C. 0.04 moles
D. 0.08 moles
E. 0.12 moles

6	8	11
C	O	Na
12.01	16.00	23.00

$$1Na_2CO_3 \rightarrow 2Na + 1C + 3O$$

M_W of Na_2CO_3:

$$2(23\ g/mol) + (12.01\ g/mol) + 3(16.00\ g/mol) = 106\ g/mol$$

Grams molecules → Moles molecules → Moles Na atoms

$$4.4\ g\ \cancel{Na_2CO_3} \times \frac{1\ \cancel{mol\ Na_2CO_3}}{106\ g\ \cancel{Na_2CO_3}} \times \frac{\boxed{2\ mol\ Na}}{1\ \cancel{mol\ Na_2CO_3}}$$

Your answer will have units of moles of Na

Topic 14 Learning Goals

As a student, I am able to:

1	identify the limiting and excess reagents in a chemical reaction based on given amounts of reactants
2	use the chemical equation to compute the maximum amount (theoretical yield) of products produced
3	use the chemical equation to compute the amount of reactants needed to produce a 100% yield
4	use the chemical equation to predict all masses of all components after a reaction has run to 100% completion: i.e. amount of reactant reacted, amount of reactant unreacted (excess), amount of product produced
5	recognize the actual yield in a chemical reaction based on the wording of a problem
6	compute percent yields for any chemical reaction from actual yields and theoretical yields
7	incorporate limiting reagent calculations into *all* stoichiometric calculations starting with given amounts of reactants or given amounts of products
8	for any given set of conditions compute the amount of reactants and products in the reaction vessel (including mole, mass, % yield and or number of particles)

Topic 14 Material

Mole Ratios and Limiting Reagent
Identify the limiting and excess reagents for a balanced chemical reaction.
Compute the maximum amount (theoretical yield) of products produced and the amount of reactant unreacted (excess)

% yield = (Actual/theoretical)*100
Recognize actual yield, theoretical yield and % yield.
Apply percent yield calculations to any stoichiometry problem.

T14Q1: Level 1 (L.G. 1)

When 2.5 moles of $CaCO_3$ is added to 4.8 moles of HCl, $CaCl_2$, CO_2 and H_2O are produced by the following chemical reaction:

$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

What species is the limiting reagent in this reaction?

- **A. Calcium carbonate**
- **B. Hydrochloric acid**
- **C. Calcium chloride**
- **D. Carbon dioxide**
- **E. Water**

T14Q1: Solution

When 2.5 moles of $CaCO_3$ is added to 4.8 moles of HCl, $CaCl_2$, CO_2 and H_2O are produced by the following chemical reaction:

$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

What species is the limiting reagent in this reaction?

A. Calcium carbonate
B. Hydrochloric acid
C. Calcium chloride
D. Carbon dioxide
E. Water

The amount of HCl LIMITS the amount of product that can be formed! HCl is the Limiting Reagent

Reaction	$CaCO_3$ +	2HCl →	$CaCl_2$ + H_2O + CO_2
Before Rxn	2.5 moles	4.8 moles	-
LR Calcs	2.5 moles	-	2.5 moles x (1/1) = 2.5 moles
	-	4.8 moles	4.8 moles x (1/2) = 2.4 moles

T14Q2: Level 1 (L.G. 2)

Consider the reaction: **$2H_2 + O_2 \rightarrow 2H_2O$**

If 3 moles of H_2 react with 2 moles of O_2, what is the maximum number of moles of H_2O that can be produced?

A. **5 moles**

B. **4 moles**

C. **3 moles**

D. **2 moles**

T14Q2: Solution

Consider the reaction: **$2H_2 + O_2 \rightarrow 2H_2O$**

If 3 moles of H_2 react with 2 moles of O_2, what is the maximum number of moles of H_2O that can be produced?

A. 5 moles
B. 4 moles
C. 3 moles
D. 2 moles

The amount of H_2 LIMITS the amount of H_2O that can be formed! H_2 is the Limiting Reagent and ONLY 3 moles of H_2O can be produced!

Reaction	$2H_2$ +	O_2 $\rightarrow$	$2H_2O$
Before Rxn	3 moles	2 moles	-
LR Calcs	3 moles	-	3 moles x (2/2) = 3 moles
	-	2 moles	2 moles x (2/1) = 4 moles

T14Q3: Level 2 (L.G. 3)

How many moles of O_2 are required for the complete combustion of 2.2 g of C_3H_8 to form CO_2 and H_2O?

A. **0.050 moles of O_2**
B. **0.15 moles of O_2**
C. **0.25 moles of O_2**
D. **0.50 moles of O_2**

T14Q3: Solution

How many moles of O_2 are required for the complete combustion of 2.2 g of C_3H_8 to form CO_2 and H_2O?

A. **0.050 moles of O_2**
B. **0.15 moles of O_2**
C. $\boxed{\textbf{0.25 moles of } O_2}$
D. **0.50 moles of O_2**

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

M_w of C_3H_8
= 3(12.01 g/mol) + 8(1.008 g/mol)
= 44.1 g/mol

T14Q3: Solution

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M_w of C_3H_8
$= 3(12.01\ g/mol) + 8(1.008\ g/mol)$
$= 44.1\ g/mol$

Reaction	C_3H_8 +	$5O_2$	$\rightarrow$ $3CO_2 + 4H_2O$
In the vessel before rxn (no coefficient used)		-	-
		?	-
What reacted			-

T14Q3: Solution

How many moles of O_2 are required for the complete combustion of 2.2 g of C_3H_8 to form CO_2 and H_2O?

A. 0.050 moles of O_2
B. 0.15 moles of O_2
C. $\boxed{\text{0.25 moles of } O_2}$
D. 0.50 moles of O_2

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

M_w of C_3H_8
= 3(12.01 g/mol) + 8(1.008 g/mol)
= 44.1 g/mol

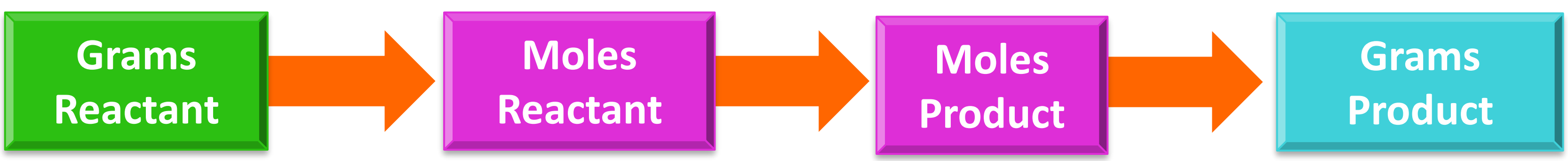
Reaction	C_3H_8 +	$5O_2$	$\rightarrow$ $3CO_2 + 4H_2O$
In the vessel before rxn (no coefficient used)	2.2 g	-	-
	2.2 g /(44.1 g/n) = 0.049 moles	?	-
What reacted	0.049 moles	0.049 moles x (5/1) = 0.25 moles	-

T14Q4: Level 3 (L.G. 4)

Calculate the maximum amount of aluminum oxide (Al_2O_3) that could be produced if 2.5 g of Al react with 2.5 g of oxygen .

A. **4.7 g**
B. **5.3 g**
C. **7.4 g**
D. **9.4 g**

<u>Before doing any math:</u>
We need to write a balanced equation for the reaction



T14Q4: Solution

Calculate the maximum amount of aluminum oxide (Al_2O_3) that could be produced if 2.5 g of Al react with 2.5 g of oxygen .

A. 4.7 g

B. 5.3 g

C. 7.4 g

D. 9.4 g

Grams Reactant → Moles Reactant → Moles Product → Grams Product

T14Q4: Solution

Calculate the maximum amount of aluminum oxide (Al_2O_3) that could be produced if 2.5 g of Al react with 2.5 g of oxygen .

Reaction	$4Al$	+ $3O_2$	→ $2Al_2O_3$
In the vessel before rxn (no coefficient used)	2.5 g	2.5 g	-
			-
LR Calcs			
In the vessel after rxn (no coefficient used)			

T14Q4: Solution

Calculate the maximum amount of aluminum oxide (Al_2O_3) that could be produced if 2.5 g of Al react with 2.5 g of oxygen .

Reaction	4Al	+ $3O_2$ →	$2Al_2O_3$
In the vessel before rxn (no coefficient used)	2.5 g	2.5 g	-
	2.5g/(26.98g/mol) = 0.093 mol	2.5g/(32g/mol) = 0.078 mol	-
LR Calcs	0.093 mol	-	0.093 x (2/4) = 0.0465 mol
	-	0.078 mol	0.078 x (2/3) = 0.052 mol
In the vessel after rxn (no coefficient used)	-	-	0.0465 mol
	-	-	0.0465mol x (101.96 g/mol) = 4.74 g

T14Q5: Level 2 (L.G. 4)

For the reaction $\mathbf{N_2 + 3H_2 \rightarrow 2NH_3}$,
If you react 21 g hydrogen with 56 g nitrogen, what is the maximum number of grams of NH_3 that can be formed?

A. **34 g**
B. **68 g**
C. **70 g**
D. **79 g**

7	1
N	**H**
14.01	1.008

T14Q5: Solution

For the reaction **$N_2 + 3H_2 \rightarrow 2NH_3$,**
If you react 21 g hydrogen with 56 g nitrogen, what is the maximum number of grams of NH_3 that can be formed?

A. 34 g

B. 68 g

C. 70 g

D. 79 g

7	1
N	H
14.01	1.008

Step 1 Step 2 Step 3 Step 4

Grams Reactant → Moles Reactant → Moles Product → Grams Product

T14Q5: Solution

For the reaction $N_2 + 3H_2 \rightarrow 2NH_3$, Step 1
If you react 21 g hydrogen with 56 g nitrogen, what is the maximum number of grams of NH_3 that can be formed?

Step 2

21 g H_2 / (2.016 g/mol) $\rightarrow$ 10.41 moles H_2
56 g N_2 / (28.02g/mol) $\rightarrow$ 1.99 moles N_2

7	1
N	H
14.01	1.008

Step 3

Ratio H_2 to NH_3 is 3:2
10.41 moles H_2 * ($2NH_3$ /$3H_2$) = 6.94 moles NH_3
Ratio N_2 to NH_3 is 1:2
1.99 moles N_2 * ($2NH_3$ / $1N_2$) = 3.98 moles NH_3

N_2 is the limiting reagent

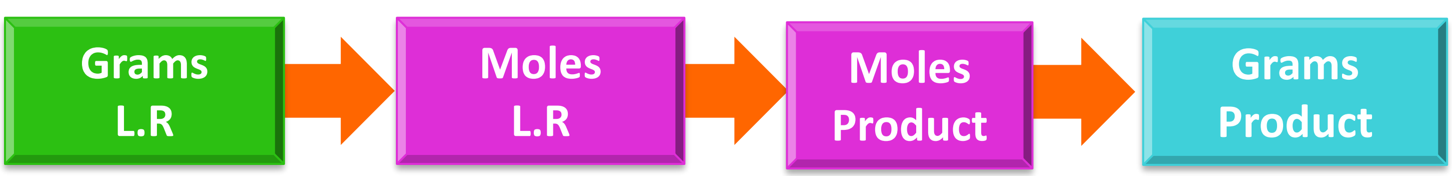
Step 4

(3.98 moles NH_3) * (17.034 g/mol) = <u>67.8 grams NH_3</u>

T14Q6: Level 2 (L.G. 4)

Consider the chemical reaction that occurs when iron(III) oxide reacts with carbon to produce iron metal and carbon dioxide: **$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$** If 13.00 g of Fe_2O_3 reacts completely with 4.20 g of C, how much Fe will be formed?

A. 26.08 g
B. 19.54 g
C. 9.05 g
D. 4.52 g
E. 2.26 g



T14Q6: Solution

Consider the chemical reaction that occurs when iron(III) oxide reacts with carbon to produce iron metal and carbon dioxide: $\mathbf{2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2}$ If 13.00 g of Fe_2O_3 reacts completely with 4.20 g of C, how much Fe will be formed?

A. **26.08 g**
B. **19.54 g**
C. **9.05 g**
D. **4.52 g**
E. **2.26 g**

Theoretical Yield
100% product

Grams LR → **Moles LR** → **Moles Product** → **Grams Product**

T14Q6: Solution

Consider the chemical reaction that occurs when iron(III) oxide reacts with carbon to produce iron metal and carbon dioxide: **$2Fe_2O_3 + 3C \rightarrow 4Fe + 3CO_2$** If 13.00 g of Fe_2O_3 reacts completely with 4.20 g of C, how much Fe will be formed?

Fe_2O_3	C
13 g /(159.7 g/mol) = 0.081 moles	**4.2 g /(12.01 g/mol) = 0.350 moles**
0.081 n x (4/2) = 0.162 moles Fe	**0.350 n x (4/3) = 0.467 moles Fe**
Theoretical Yield: (grams of product formed if all LR reacts) **0.162 moles x (55.85 g/mol) = 9.05 grams Fe**	

T14Q7: Level 3 (L.G. 8)

Consider the chemical reaction that occurs when sodium metal reacts with oxygen gas: **$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$**
How many grams of sodium oxide are produced when 5.00 g of sodium and 5.00 g of oxygen react and a 84% yield of sodium oxide is obtained.

A. **5.64 grams**
B. **6.73 grams**
C. **8.33 grams**
D. **9.92 grams**

Grams L.R → **Moles L.R** → **Moles Product** → **Grams Product** → **% Yield Calculation**

T14Q7: Solution

Consider the chemical reaction that occurs when sodium metal reacts with oxygen gas: **$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$**
How many grams of sodium oxide are produced when 5.00 g of sodium and 5.00 g of oxygen react and a 84% yield of sodium oxide is obtained.

A. **5.64 grams**
B. **6.73 grams**
C. **8.33 grams**
D. **9.92 grams**

Theoretical Yield
100% product

T14Q7: Solution

Consider the chemical reaction that occurs when sodium metal reacts with oxygen gas: **$4Na(s) + O_2(g) \rightarrow 2Na_2O(s)$**
How many grams of sodium oxide are produced when 5.00 g of sodium and 5.00 g of oxygen react and a 84% yield of sodium oxide is obtained.

Na	O_2
5 g /(23 g/mol) = 0.217 moles	5 g /(32g/mol) = 0.16 moles
0.217 n x (2/4) = 0.1085 moles Na_2O	0.16 n x (2/1) = 0.32 moles Na_2O
Theoretical Yield: 0.1085 moles x (61.98 g/mol) = 6.73 grams Na_2O	
Actual yield = (6.73 g)*(84%/100%) = 5.64 g Na_2O	

T14Q8: Level 3 (L.G. 8)

Consider the following chemical reaction:

$NaHCO_3(aq) + HCl(aq) \rightarrow H_2CO_3\,(aq) + NaCl(aq)$

How many grams of hydrogen carbonate are produced if you react 2.8 g of sodium hydrogen carbonate with 3.1 g of hydrochloric acid and the yield is 45%.

- **A.** **5.27 grams**
- **B.** **2.37 grams**
- **C.** **2.07 grams**
- **D.** **0.93 grams**

Grams L.R → **Moles L.R** → **Moles Product** → **Grams Product** → **% Yield Calculation**

T14Q8: Solution

Consider the following chemical reaction:

$NaHCO_3(aq) + HCl(aq) \rightarrow H_2CO_3(aq) + NaCl(aq)$

How many grams of hydrogen carbonate are produced if you react 2.8 g of sodium hydrogen carbonate with 3.1 g of hydrochloric acid and the yield is 45%.

A. 5.27 grams
B. 2.37 grams
C. 2.07 grams
D. 0.93 grams

Theoretical Yield
100% product

Grams Reactant → **Moles Reactant** → **Moles Product** → **Grams Product** → **% Yield Calculation**

T14Q8: Solution

Consider the following chemical reaction:

$NaHCO_3(aq) + HCl(aq) \rightarrow H_2CO_3\,(aq) + NaCl(aq)$

How many grams of hydrogen carbonate are produced if you react 2.8 g of sodium hydrogen carbonate with 3.1 g of hydrochloric acid and the yield is 45%.

$NaHCO_3$	HCl
2.8 g /(84.007 g/mol) = 0.033 moles	3.1 g /(36.46g/mol) = 0.085 moles
0.033 n x (1/1) = 0.033 moles H_2CO_3	0.085 n x (1/1) = 0.085 moles H_2CO_3
Theoretical Yield: 0.033 moles x (62.03 g/mol) = 2.07 grams H_2CO_3	
Actual yield = (2.07 g)*(45%/100%) = 0.93 g H_2CO_3	

T14Q9: Level 3 (L.G. 8)

When 2.5 moles of calcium carbonate is added to 4.8 moles of hydrochloric acid, calcium chloride, carbon dioxide, and water are produced: **$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$**
Which calculation represents the number of *grams* of calcium chloride that are produced if the reaction proceeds with a 65% yield?

A. **2.5 moles $CaCl_2$ * 110.98 grams/mol * 0.65**
B. **2.4 moles $CaCl_2$ * 110.98 grams/mol * 0.65**
C. **2.5 moles $CaCl_2$ * 110.98 grams/mol / 0.65**
D. **2.4 moles $CaCl_2$ * 110.98 grams/mol / 0.65**

T14Q9: Solution

When 2.5 moles of calcium carbonate is added to 4.8 moles of hydrochloric acid, calcium chloride, carbon dioxide, and water are produced: **$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$**
Which calculation represents the number of *grams* of calcium chloride that are produced if the reaction proceeds with a 65% yield?

A. 2.5 moles $CaCl_2$ * 110.98 grams/mol * 0.65
B. 2.4 moles $CaCl_2$ * 110.98 grams/mol * 0.65
C. 2.5 moles $CaCl_2$ * 110.98 grams/mol / 0.65
D. 2.4 moles $CaCl_2$ * 110.98 grams/mol / 0.65

Moles LR → Moles Product → Grams Product → % Yield Calculation

T14Q9: Solution

B. 2.4 moles $CaCl_2$ * 110.98 grams/mol * 0.65

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

2.5 moles 4.8 moles 65% yield

2.5 moles $CaCO_3$ x (1/1) = 2.5 moles $CaCl_2$

4.8 moles HCl x (1/2) = 2.4 moles $CaCl_2$

HCl is the limiting reagent and you can only make 2.4 moles of $CaCl_2$

Moles LR → Moles Product → Grams Product → % Yield Calculation

$$2.4 \text{ moles } CaCl_2 \times \frac{110.98 \text{ g } CaCl_2}{1 \text{ mole } CaCl_2} \times \frac{65\ \%}{100\%}$$

Topic 14b&15

Stoichiometry & Empirical Formula

Stoicheion = Element

+ Metron = Measure

STOICHIOMETRY

Peer Instruction
Clicker Session 16

8 pt Question

Consider the reaction: **$4Fe + 3O_2 \rightarrow 2Fe_2O_3$**

If 4 moles of Fe react with 4 moles of O_2 and the reaction has a 84% yield, how many moles of the excess reagent are left over?

A. **3.57 moles**

B. **3.00 moles**

C. **2.52 moles**

D. **1.48 moles**

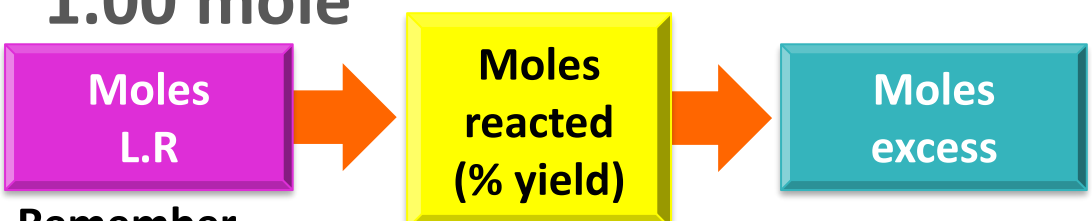
E. **1.00 mole**

8pt Question: Solution

Consider the reaction: **$4Fe + 3O_2 \rightarrow 2Fe_2O_3$**

If 4 moles of Fe react with 4 moles of O_2 and the reaction has a 84% yield, how many moles of the excess reagent are left over?

- **A.** 3.57 moles
- **B.** 3.00 moles
- **C.** 2.52 moles
- **D.** 1.48 moles
- **E.** 1.00 mole



Remember that the L.R is ALL consumed!

8 pt Question: Solution

Consider the reaction: **$4Fe + 3O_2 \rightarrow 2Fe_2O_3$**

If 4 moles of Fe react with 4 moles of O_2 and the reaction has a 84% yield, how many moles of the excess reagent are left over?

4Fe	**$3O_2$**
4 moles	**4 moles**
4n x (2/4) = 2 moles Fe_2O_3	**4n x (2/3) = 2.7 moles Fe_2O_3**
Moles Fe actually reacted = 4 x (84/100) = 3.36 moles Fe	
Moles O_2 reacted = 3.36 x (3/4) = 2.52 moles O_2 reacted	
Excess O_2 (moles) = 4 moles – 2.52 moles = 1.48 mole	

T14Q1: Level 4 (L.G. 8)

An aqueous solution containing 7.60 g of lead(II) nitrate is added to an aqueous solution containing 7.39 g of potassium chloride. If the percent yield is 84.0%, how many grams of excess reagent remain after the reaction is complete?

A. **5.66 g**
B. **4.50 g**
C. **3.33 g**
D. **0.0604 g**

T14Q1: Solution HINT

An aqueous solution containing 7.60 g of lead(II) nitrate is added to an aqueous solution containing 7.39 g of potassium chloride. If the percent yield is 84.0%, how many grams of excess reagent remain after the reaction is complete?

A. 5.66 g
B. 4.50 g
C. 3.33 g
D. 0.0604 g

Write a balanced equation first!

$$Pb(NO_3)_2(aq) + 2KCl(aq) \rightarrow PbCl_2(s) + 2KNO_3(aq)$$

Now find the limiting reagent

Grams L.R → **Moles L.R** → **Moles reacted (% yield)** → **Moles excess** → **Grams excess**

Remember that the L.R is ALL consumed!

T14Q1: Solution

An aqueous solution containing 7.60 g of lead(II) nitrate is added to an aqueous solution containing 7.39 g of potassium chloride. If the percent yield is 84.0%, how many grams of excess reagent remain after the reaction is complete?

A. 5.66 g
B. 4.50 g
C. 3.33 g
D. 0.0604 g

Write a balanced equation first!

$$Pb(NO_3)_2(aq) + 2KCl(aq) \rightarrow PbCl_2(s) + 2KNO_3(aq)$$

Now find the limiting reagent

Grams L.R → Moles L.R → Moles reacted (% yield) → Moles excess → Grams excess

Remember that the L.R is ALL consumed!

T14Q1: Solution

An aqueous solution containing 7.60 g of lead(II) nitrate is added to an aqueous solution containing 7.39 g of potassium chloride. If the percent yield is 84.0%, how many grams of excess reagent remain after the reaction is complete?

$$Pb(NO_3)_2(aq) + 2KCl(aq) \rightarrow PbCl_2(s) + 2KNO_3(aq)$$

$Pb(NO_3)_2$	KCl
7.6 g /(331.12 g/n) = 0.023 moles	7.39 g /(74.55g/n) = 0.099 moles
0.023 n x (1/1) = 0.023 moles $PbCl_2$	0.099 n x (1/2) = 0.0495 moles $PbCl_2$
Moles KCl reacted = 0.023 x (2/1) x (84%/100%) = 0.0386 moles	
Excess KCl (moles) = 0.099 moles - 0.0386 moles = 0.0604 moles	
Excess KCl (grams) = 0.0604moles x (74.55 g/mol) = 4.50 grams KCl	

T14Q2: Level 3+ (L.G. 8)

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

What mass of magnetite is required to obtain 4.0 kg of iron if the process only runs to 66% completion?

A. **3.65 kg**
B. **5.53 kg**
C. **6.10 kg**
D. **7.91 kg**
E. **8.37 kg**

T14Q2: Solution HINT

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

What mass of magnetite is required to obtain 4.0 kg of iron if the process only runs to 66% completion?

A. 3.65 kg
B. 5.53 kg
C. 6.10 kg
D. 7.91 kg
E. 8.37 kg

We are given a balanced equation

We are given the Actual & % yield of the product.

% yield = actual (g)/ theoretical(g) X 100%

Find the theoretical yield and then work backwards

Grams Reactant ← **Moles Reactant** ← **Moles Product** ← **Grams Product** ← **% Yield Calculation**

T14Q2: Solution

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

What mass of magnetite is required to obtain 4.0 kg of iron if the process only runs to 66% completion?

A. 3.65 kg
B. 5.53 kg
C. 6.10 kg
D. 7.91 kg
E. 8.37 kg

We are given a balanced equation

We are given the Actual & % yield of the product.

% yield = actual (g)/ theoretical(g) X 100%

Find the theoretical yield and then work backwards

Grams Reactant ← **Moles Reactant** ← **Moles Product** ← **Grams Product** ← **% Yield Calculation**

T14Q2: Solution

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

What mass of magnetite is required to obtain 4.0 kg of iron if the process only runs to 66% completion?

We know that: % yield = actual product (g)/theoretical yield (g) X 100%

Rearrange Eq: theoretical yield (g) = actual product (g)/ % yield X 100%

Fe_3O_4	3Fe(s)
Theoretical yield = (4000 g Fe)*100/(66) = 6060 g Fe	
6060 g Fe / (55.85 g/mol) = 108.5 moles Fe	
108.5 n x (1/3) = 36.17 n Fe_3O_4	-
36.17 n x (231.55 g/n) = 8375 g Fe_3O_4	-

Topic 15 Learning Goals

As a student, I am able to:

1	compute % composition for any element based on the chemical formula of a compound
2	obtain the empirical formula from mass measurements, % composition and chemical reactions
3	obtain molecular formulas from empirical formulas and molecular weight data
4	determine empirical and molecular formula from combustion reactions

Topic 15 Material

Empirical and Molecular Formulas
Obtain the **empirical formula** from mass measurement and % composition.
Obtain **molecular formulas** from empirical formulas and MWs
Percent Composition
Compute **% composition** for any element (or group) based on the chemical formula of the compound
$\% \text{ Comp.} = \dfrac{\text{Mass of element in compound}}{\text{Total mass of compound}} \times 100\%$
Combustion reactions
Obtain the **empirical formula** and/or **molecular formulas** for any compound based on the products of combustion reactions.

Empirical and Molecular Formula

Empirical formula: Simplest whole number mole ratio of atoms within a molecule

Mass % of each element → (Assume 100g of sample) → Grams of each element → (Use the molecular weight) → Moles of each element → (Calculate the simplest mole ratio) → Empirical Formula

Molecular Formula: Actual whole number atomic (mole) ratio of a compound

Mw of empirical formula → Ratio of E.F. Mw and given Mw → Multiply E.F by Mw ratio

T15Q1: Level 1 (L.G. 2)

Which of the following represent an empirical formula?

A. $C_2H_4O_6$
B. S_8
C. N_2H_5S
D. C_6H_6

T15Q1: Solution

Which of the following represent an empirical formula?

A. $C_2H_4O_6$ → divide by 2: CH_2O_3

B. S_8 → divide by 8: S

C. $\boxed{N_2H_5S}$

D. C_6H_6 → divide by 6: CH

Empirical formula: Simplest whole number mole ratio of atoms within a compound

Also note the molecular formula: Actual whole number atomic (mole) ratio of a compound

T15Q2: Level 1 (L.G. 3)

Determine the Molecular Formula of Cadinene if it has a molar mass of 204 g/mol and an empirical formula of C_5H_8

A. $C_{20}H_{32}$
B. $C_{15}H_{24}$
C. $C_{7.5}H_{12}$
D. $C_{10}H_{16}$

1	6
H	C
1.008	12.00

T15Q2: Solution

Determine the Molecular Formula of Cadinene if it has a molar mass of 204 g/mol and an empirical formula of C_5H_8

A. $C_{20}H_{32}$

B. $\boxed{C_{15}H_{24}}$

C. $C_{7.5}H_{12}$

D. $C_{10}H_{16}$

1 **H** 1.008	6 **C** 12.00

Mw of given compound → (Determine mass of EF) → **Ratio of Mw to mass of EF** → (Multiply EF by Ratio) → **Molecular Formula**

T15Q2: Solution

Determine the Molecular Formula of Cadinene if it has a molar mass of 204 g/mol and an empirical formula of C_5H_8

Mw of given compound → Determine mass of EF → Ratio of Mw to mass of EF → Multiply EF by Ratio → Molecular Formula

Mw of compound = 204 g/mol

Molar mass of C_5H_8 = 5(12.01) + 8(1.008) = 68.11 g/mol

(204 g/mol)/(68.11 g/mol) = 2.995 ~3

$$(C_5H_8) \times 3 = \boxed{C_{15}H_{24}}$$

Molecular formula

T15Q3: Level 2 (L.G. 2)

Find the empirical formula of a compound that contains 48.38 g carbon, 8.12 g hydrogen, and 43.5 g oxygen.

A. $C_{12}H_{24}O_5$
B. $C_5H_8O_4$
C. $C_3H_6O_2$
D. CH_3O

1	6	8
H	C	O
1.008	12.00	16.00

T15Q3: Solution

Find the empirical formula of a compound that contains 48.38 g carbon, 8.12 g hydrogen, and 43.5 g oxygen.

Grams of each element → Use the atomic mass → **Moles of each element** → Simplest integer mole ratio → **Empirical Formula (EF)**

Atom	C	H	O
grams	48.38 g	8.12 g	43.5 g
moles	48.38/12.01 = 4.03 mol	8.12/1.008 = 8.06 mol	43.3/16.00 = 2.71 mol
Empirical formula	4.03/2.71 = 1.5 x 2	8.06/2.71 = 3 x 2	2.71/2.71 = 1 x 2
	3	6	2

$C_3H_6O_2$

T15Q4: Level 2 (L.G. 3)

The composition of adipic acid is 49.3% C, 6.9% H, and 43.8% O (by mass). The molar mass of the compound is 146 g/mol.

What is the **molecular formula** of adipic acid?

- **A.** C_7HO_6
- **B.** $C_{1.5}H_{2.5}O_1$
- **C.** $C_3H_5O_2$
- **D.** $C_6H_{10}O_4$

1	6	8
H	C	O
1.008	12.00	16.00

T15Q4: Solution

The composition of adipic acid is 49.3% C, 6.9% H, and 43.8% O (by mass). The molar mass of the compound is 146 g/mol.

What is the **molecular formula** of adipic acid?

1	6	8
H	C	O
1.008	12.00	16.00

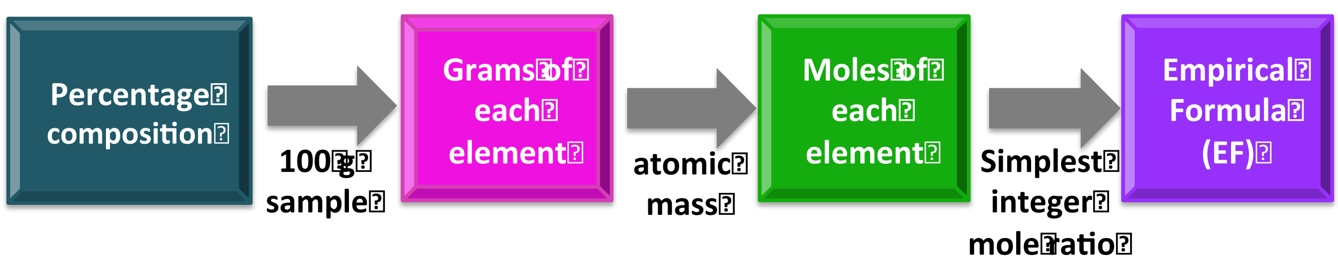
A. C_7HO_6

B. $C_{1.5}H_{2.5}O_1$ — Mw = 146 g/mol

C. $C_3H_5O_2$ — Mw = 146 g/mol

D. $\boxed{C_6H_{10}O_4}$ — Mw = 146 g/mol

We don't know which one is right!. We MUST find EF first and then look at the Mw ratios!



T15Q4: Solution

The composition of adipic acid is 49.3% C, 6.9% H, and 43.8% O (by mass). The molar mass of the compound is 146 g/mol.

What is the **molecular formula** of adipic acid?

Atom	C	H	O
Percent	49.3 %	6.9 %	43.8 %
grams	49.3 g	6.9 g	43.8 g
moles	49.3/12.01 = 4.11 mol	6.9/1.008 = 6.85mol	43.8/16.00 = 2.74 mol
Empirical formula	4.11/2.74 = 1.5 x 2	6.85/2.74 = 2.5 x 2	2.74/2.74 = 1 x 2
	3	5	2

$C_3H_5O_2$

Mass of EF = 73 g/mol

Ratio = (146 g/mol)/(73 g/mol) = 2

X 2 = $C_6H_{10}O_4$

T15Q5: Level 2 (L.G. 7)

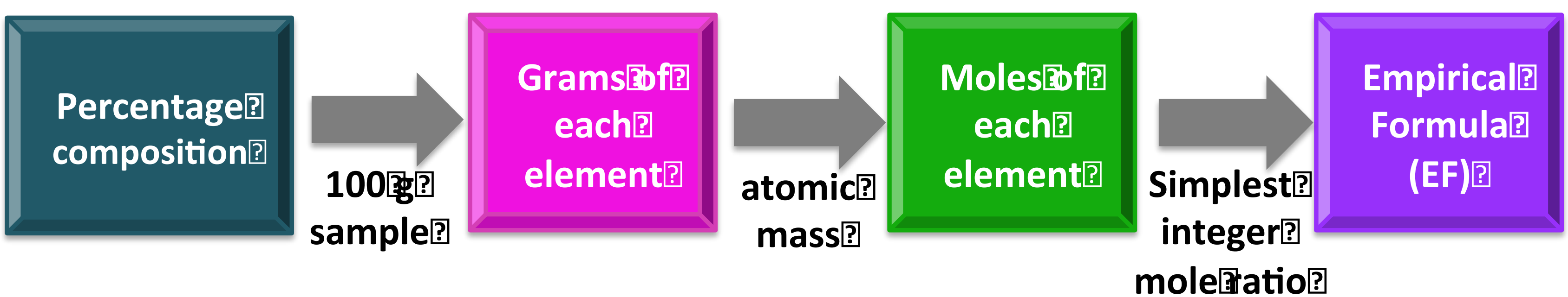
A much sought-after explosive made of exclusively carbon, nitrogen and oxygen. The explosive is known to contain 20.7% carbon and 24.1% nitrogen. What is its empirical formula?

A. CNO_2
B. C_2NO_2
C. CNO_3
D. $C_2N_2O_6$

T15Q5: Solution

A much sought-after explosive made of exclusively carbon, nitrogen and oxygen. The explosive is known to contain 20.7% carbon and 24.1% nitrogen. What is its empirical formula?

A. CNO_2
B. C_2NO_2
C. CNO_3
D. $C_2N_2O_6$



T15Q5: Solution

A much sought-after explosive made of exclusively carbon, nitrogen and oxygen. The explosive is known to contain 20.7% carbon and 24.1% nitrogen. What is its empirical formula?

Atom	C	N	O
Percent	20.7	24.1	100 - 20.7 - 24.1 = 55.2
grams	20.7	24.1	55.2
moles	20.7/12.01 = 1.72 mol	24.1/14.01 = 1.72 mol	55.2/16.00 = 3.45 mol
Empirical formula	1.72/1.72 = 1	1.72/1.72 = 1	3.45/1.72 = 2
	1	1	2

CNO_2

T15Q6: Level 3 (L.G. 2)

Once vanadium has been extracted from vanadinite ore it can be used to produce a variety of pure vanadium oxides. One such oxide was found to contain 56.02% vanadium. What is the empirical formula of this oxide?

A. V_2O_2
B. V_2O_3
C. V_2O_5
D. V_1O_3

Try these on your own at home!

T14Q4: Level 3 (L.G 8)

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

What mass of magnetite is required to obtain 5.0 kg of iron if the process only runs to 88% completion?

A. **6.1 kg**

B. **6.9 kg**

C. **7.9 kg**

D. **18 kg**

T14Q4: Solution

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

What mass of magnetite is required to obtain 5.0 kg of iron if the process only runs to 88% completion?

A. 6.1 kg

B. 6.9 kg

C. 7.9 kg

D. 18 kg

Grams Reactant ← Moles Reactant ← Moles Product ← Grams Product ← % Yield Calculation

T14Q4: Solution

Consider the production of Iron from magnetite (Fe_3O_4):

$Fe_3O_4(s) + 2CO(g) \rightarrow 3Fe(s) + 2CO_2(g) + O_2(g)$

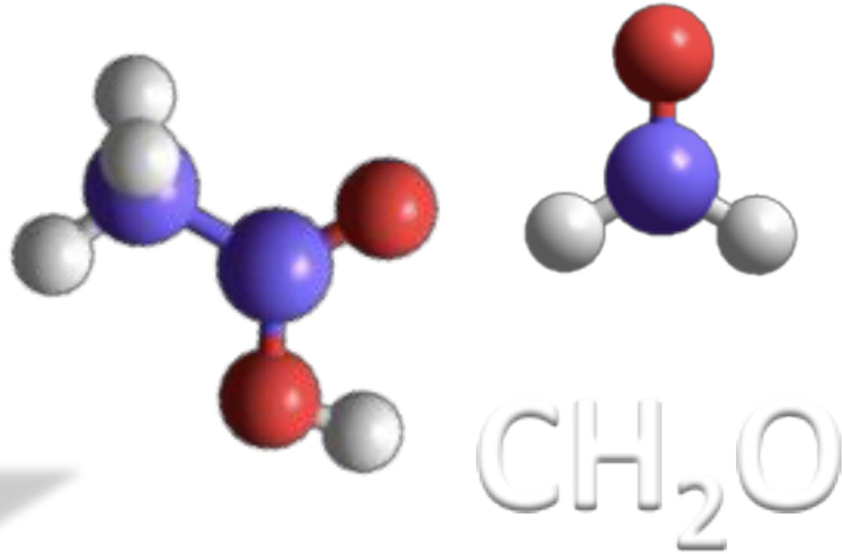
What mass of magnetite is required to obtain 5.0 kg of iron if the process only runs to 88% completion?

Percent yield = (Actual yield/theoretical yield) * 100%

Fe_3O_4	3Fe
Theoretical yield = (5000 g Fe)*100%/88% = 5681 g Fe	
5681 g Fe / (55.85 g/mol) = 101.73 moles Fe	
101.73 n x (1/3) = 33.91 n Fe_3O_4	-
33.91 n x (231.55 g/n) = 7851 g Fe_3O_4	-

Topic 15B&16

Empirical Formula



Peer Instruction Clicker Session 17

8 pt Challenge

Once vanadium has been extracted from vanadinite ore it can be used to produce a variety of pure vanadium oxides. One such oxide was found to contain 56.02% vanadium. What is the empirical formula of this oxide?

A. V_2O_2
B. V_2O_3
C. V_2O_5
D. V_1O_3

8 pt Challenge: Solution

Once vanadium has been extracted from vanadinite ore it can be used to produce a variety of pure vanadium oxides. One such oxide was found to contain 56.02% vanadium. What is the empirical formula of this oxide?

A. V_2O_2
B. V_2O_3
C. $\boxed{V_2O_5}$
D. V_1O_3

8 pt Challenge: Solution

Once vanadium has been extracted from vanadinite ore it can be used to produce a variety of pure vanadium oxides. One such oxide was found to contain 56.02% vanadium. What is the empirical formula of this oxide?

Species	V	O
%	**56.02 %**	**100 - 56.02 = 43.98%**
Grams	**56.02**	**43.98**
Moles	56.02/(50.94 g/mol) **= 1.09 mol**	43.98/(16 g/mol) **= 2.75 mol**
Mole Ratio	1.09/1.09 **= 1**	2.75/1.09 **= 2.52**

x 2

V_2O_5

Topic 15 Material

Empirical and Molecular Formulas
Obtain the **empirical formula** from mass measurement and % composition.
Obtain **molecular formulas** from empirical formulas and MWs
Percent Composition
Compute **% composition** for any element (or group) based on the chemical formula of the compound
$\% \text{ Comp.} = \dfrac{\text{Mass of element in compound}}{\text{Total mass of compound}} \times 100\%$
Combustion reactions
Obtain the **empirical formula** and/or **molecular formulas** for any compound based on the products of combustion reactions.

T15Q1: Level 2 (L.G. 1)

How many grams of sodium are in 23 g of sodium sulfate?

8	11	16
O	Na	S
16.00	22.99	32.06

A. 32 g
B. 7.45 g
C. 6.57 g
D. 3.73 g
E. 0.710 g

T15Q1: Solution

How many grams of sodium are in 23 g of sodium sulfate?

A. 32 g
B. 7.45 g
C. 6.57 g
D. 3.73 g
E. 0.710 g

sodium sulfate:
Na_2SO_4

8	11	16
O	Na	S
16.00	22.99	32.06

M_w Na_2SO_4= = 142.04 g/mol

% Na = [2(22.99 g/mol)]/(142.04/mol)]* 100%
= 32.37 %

Grams Na = (% Na in Na_2SO_4) x mass of Na_2SO_4
= (32.37/100) x 23 g
= 7.45 g

Can do this is a single step:
Grams Na = [2(22.99 g/mol)]/(142.04/mol)] x 23g = 7.45g

T15Q2: Level 1 (L.G. 1)

The percent water in the hydrate $CuSO_4 \cdot 6H_2O$ is:

A. 40.4%

B. 6.73%

C. 9.60%

D. 57.6%

1	8	16	29
H	O	S	Cu
1.008	16.00	32.06	63.55

T15Q2: Solution

The percent water in the hydrate $CuSO_4 \cdot 6H_2O$ is:

- **A. 40.4%**
- B. 6.73%
- C. 9.60%
- D. 57.6%

1 H 1.008	8 O 16.00	16 S 32.06	29 Cu 63.55

$$\% \text{ Comp.} = \frac{\text{Mass of element in compound}}{\text{Total mass of compound}} \times 100\%$$

M_w H_2O = 18.02 g/mol

M_w $CuSO_4 \cdot 6H_2O$

= 63.55 g/mol + 32.06 g/mol + 4(16.00 g/mol) + 6(18.02 g/mol)

= 267.73 g/mol

% H_2O = [6(18.02 g/mol)]/(267.73/mol)]* 100 %

= 40.38 %

T15Q3: Level 3 (L.G. 4)

Combustion of a 0.9835 g sample of a compound containing only C, H, and O produced 1.900 g of CO_2 and 1.072 g of H_2O. What is the empirical formula of the compound?

A. C_2H_5O
B. $C_2H_5O_2$
C. $C_4H_{10}O_2$
D. $C_4H_{11}O_2$

T15Q3: Solution

Combustion of a 0.9835 g sample of a compound containing only C, H, and O produced 1.900 g of CO_2 and 1.072 g of H_2O. What is the empirical formula of the compound?

A. C_2H_5O

B. $C_2H_5O_2$

C. $C_4H_{10}O_2$

D. $\boxed{C_4H_{11}O_2}$

T15Q3: Solution

Combustion of a 0.9835 g sample of a compound containing only C, H, and O produced 1.900 g of CO_2 and 1.072 g of H_2O. What is the empirical formula of the compound?

$$C_xH_yO_z + O_2 \rightarrow CO_2 + H_2O$$

$C_xH_yO_z$	O_2	CO_2	H_2O
0.9835 g	???	1.900 g	1.072 g

$$\left(\frac{12.01\ \text{g/mol}}{44.01\ \text{g/mol}}\right) \times (1.900\ \text{g})$$

= 0.518 g C

$$\left(\frac{2.016\ \text{g/mol}}{18.02\ \text{g/mol}}\right) \times (1.072\ \text{g})$$

= 0.120 g H

0.9835 g – (0.518 g + 0.120 g) = 0.345 g O

T15Q3: Solution

Combustion of a 0.9835 g sample of a compound containing only C, H, and O produced 1.900 g of CO_2 and 1.072 g of H_2O. What is the empirical formula of the compound?

$$C_xH_yO_z + O_2 \rightarrow CO_2 + H_2O$$

$$\frac{0.518 \text{ g C}}{12.01 \text{ g/mol}} \qquad \frac{0.120 \text{ g H}}{1.008 \text{ g/mol}} \qquad \frac{0.345 \text{ g O}}{16.00 \text{ g/mol}}$$

$$\frac{C_{0.0432} \quad H_{0.120} \quad O_{0.0216}}{0.0216 \quad 0.0216 \quad 0.0216}$$

$$\left(C_{2.00}H_{5.51}O_{1}\right) \times 2 \rightarrow C_4H_{11}O_2$$

T15Q4: Level 3 (L.G. 4)

An unknown compound has the formula $C_xH_yO_z$. When 0.200 g of the compound is burned in oxygen you isolate 0.293 g of CO_2 and 0.120 g of H_2O. If the experimentally determined molar mass of the compound is 60.07 g/mol, what is its molecular formula?

A. CH_2O
B. $C_2H_4O_2$
C. $C_2H_2O_2$
D. C_2H_2O

T15Q4: Solution

An unknown compound has the formula $C_xH_yO_z$. When 0.200 g of the compound is burned in oxygen you isolate 0.293 g of CO_2 and 0.120 g of H_2O. If the experimentally determined molar mass of the compound is 60.07 g/mol, what is its molecular formula?

A. CH_2O

B. $\boxed{C_2H_4O_2}$

C. $C_2H_2O_2$

D. C_2H_2O

T15Q4: Solution

An unknown compound has the formula $C_xH_yO_z$. When 0.200 g of the compound is burned in oxygen you isolate 0.293 g of CO_2 and 0.120 g of H_2O. If the experimentally determined molar mass of the compound is 60.07 g/mol, what is its molecular formula?

Atom	C	H	O
Mass (grams)	(12.01/44.01) x 0.293 g **= 0.07996**	(2.016/18.02) x 0.120 g **= 0.01343**	0.2 - 0.07996 - 0.01343 **= 0.10661**
Moles	0.07996/12.01 **= 0.00666**	0.01343/1.008 **= 0.01332**	0.10661/16.00 **= 0.00666**
EF mole Ratio	0.00666/0.00666 **= 1**	0.01332/0.00666 **= 2.000**	0.00666/0.00666 **= 1.000**
	1	**2**	**1**

CH_2O

X 2

$= C_2H_4O_2$

Mass of EF: 12.01 + 2(1.008) + 16.00 = 30.026 g/mol

(60.07 g/mol)/(30.026 g/mol) = 2

T15Q5: Level 3 (L.G. 4)

Prior to their phaseout in the 1980s, chemicals containing lead were commonly added to gasoline as anti-knocking agents. A 8.943 g sample of one such additive containing only lead, carbon and hydrogen was burned in an oxygen rich environment. The products of the combustion were 9.795 g of CO_2 and 5.035 g of H_2O. The *sum* of the subscripts in the empirical formula of the lead additive is:

A. **36**
B. **30**
C. **29**
D. **26**

T15Q5: Solution

Prior to their phaseout in the 1980s, chemicals containing lead were commonly added to gasoline as anti-knocking agents. A 8.943 g sample of one such additive containing only lead, carbon and hydrogen was burned in an oxygen rich environment. The products of the combustion were 9.795 g of CO_2 and 5.035 g of H_2O. The *sum* of the subscripts in the empirical formula of the lead additive is:

A. 36

B. 30

C. 29

D. 26

T15Q5: Solution

A **8.943 g** sample containing only lead, carbon and hydrogen was burned in an oxygen rich environment. The products of the combustion were **9.795 g of CO_2 and 5.035 g of H_2O**.

Atom	Pb	C	H
Mass (grams)	8.943 – 2.673 – 0.563 **= 5.707**	(12.01/44.01) x 9.795g **= 2.673**	(2.016/18.015) x 5.035 g **= 0.563**
Moles	5.707/207.2 **= 0.028**	2.673/12.01 **= 0.223**	0.563/1.008 **= 0.559**
EF mole Ratio	0.028/0.028 **= 1**	0.223/0.028 **= 7.96**	0.559/0.028 **= 19.96**
	1	**8**	**20**

1 + 8 + 20 = 29

T15Q6: Level 3 (L.G. 2)

Carnotite (**$K_2(UO_2)_2(VO_4)_2$**) and is one of 3 common vanadium ores. Vanadium metal can be extracted from this ore as pure vanadium. If you start with 985 g of carnotite, what is the maximum number of grams of V that can be extracted?

A. **59.2 grams**
B. **98.5 grams**
C. **118 grams**
D. **120 grams**
E. **130 grams**

T15Q6: Solution

Carnotite ($K_2(UO_2)_2(VO_4)_2$) and is one of 3 common vanadium ores. Vanadium metal can be extracted from this ore as pure vanadium. If you start with 985 g of carnotite, what is the maximum number of grams of V that can be extracted?

A. 59.2 grams
B. 98.5 grams
C. $\boxed{\text{118 grams}}$
D. 120 grams
E. 130 grams

% V in $K_2(UO_2)_2(VO_4)_2$:

$$=[(\#V)(M_w\ V)/M_w\ K_2(UO_2)_2(VO_4)_2\ ] \times 100\%$$
$$= [2(50.94)/(848.12\ g/mol)] \times 100\%$$
$$= 12.01\%$$

Mass of V that can be extracted:

$$= (12.01/100) \times (985\ g)$$
$$= 118.32\ g$$

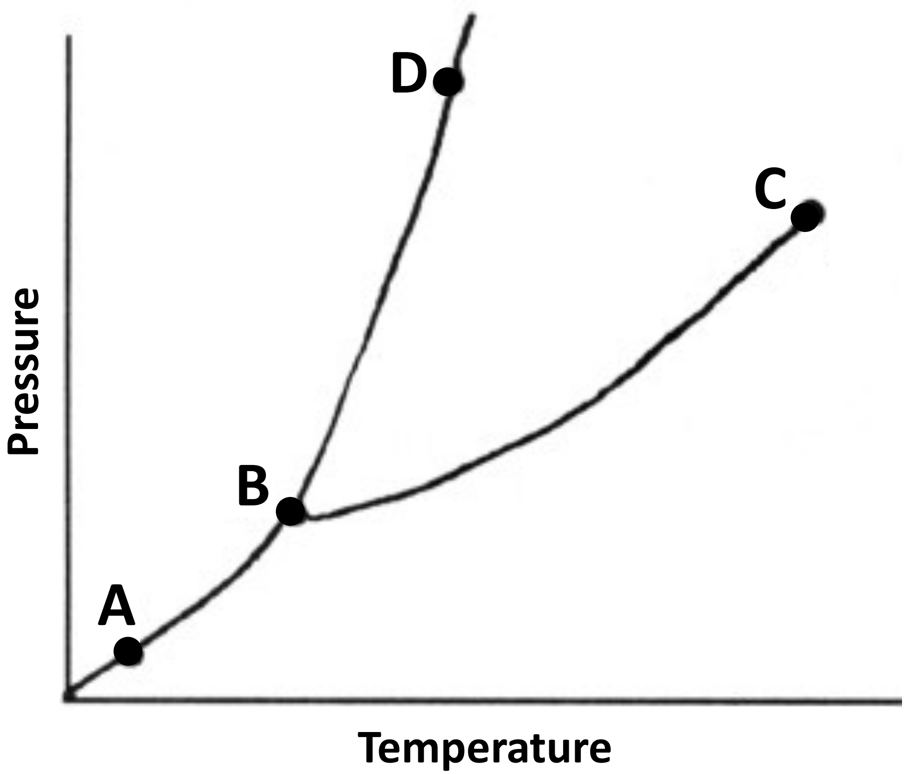
Topic 16 Material

Phase diagrams and heating curves
Recognize evaporation, condensation, freezing, melting, sublimation, and deposition and draw particle diagrams
Interpret and know how to read phase diagrams and heating curves
Intermolecular Forces
Describe both intermolecular and intramolecular forces
Describe LDFs, Dipole-dipole interactions and hydrogen bonds and rank their relative strengths
Describe/Predict the IMF’s for a given substance when given its name or chemical structure

T16Q1: Level 1 (L.G. 3)

Which segment on the phase diagram below corresponds to the equilibrium between a liquid and a vapor?

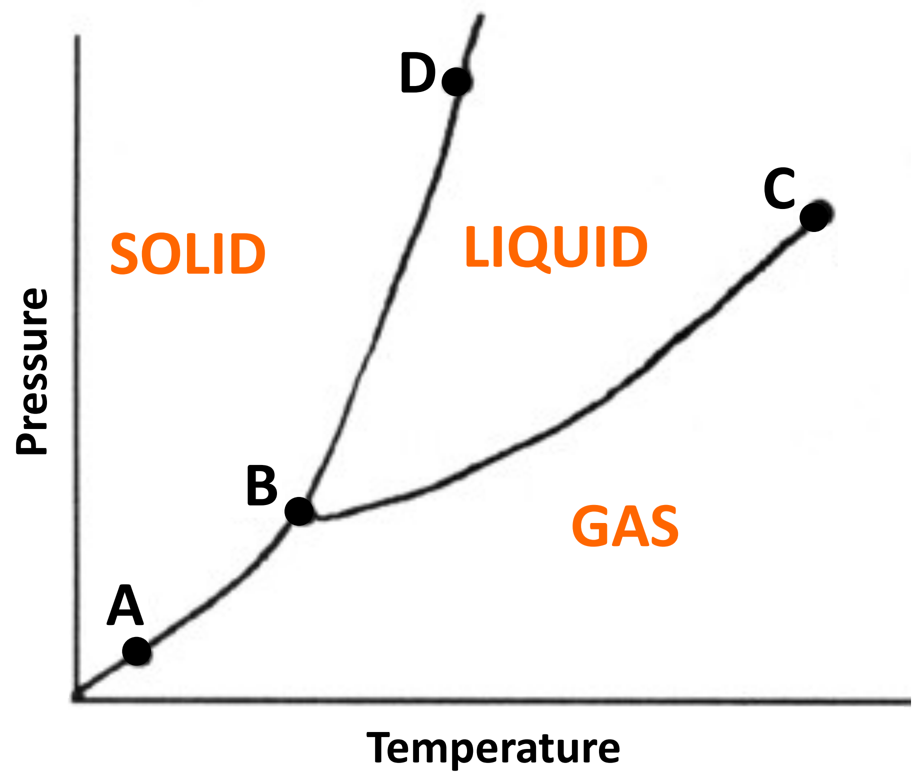
A. AB
B. AD
C. BC
D. BD



T16Q1: Solution

Which segment on the phase diagram below corresponds to the equilibrium between a liquid and a vapor?

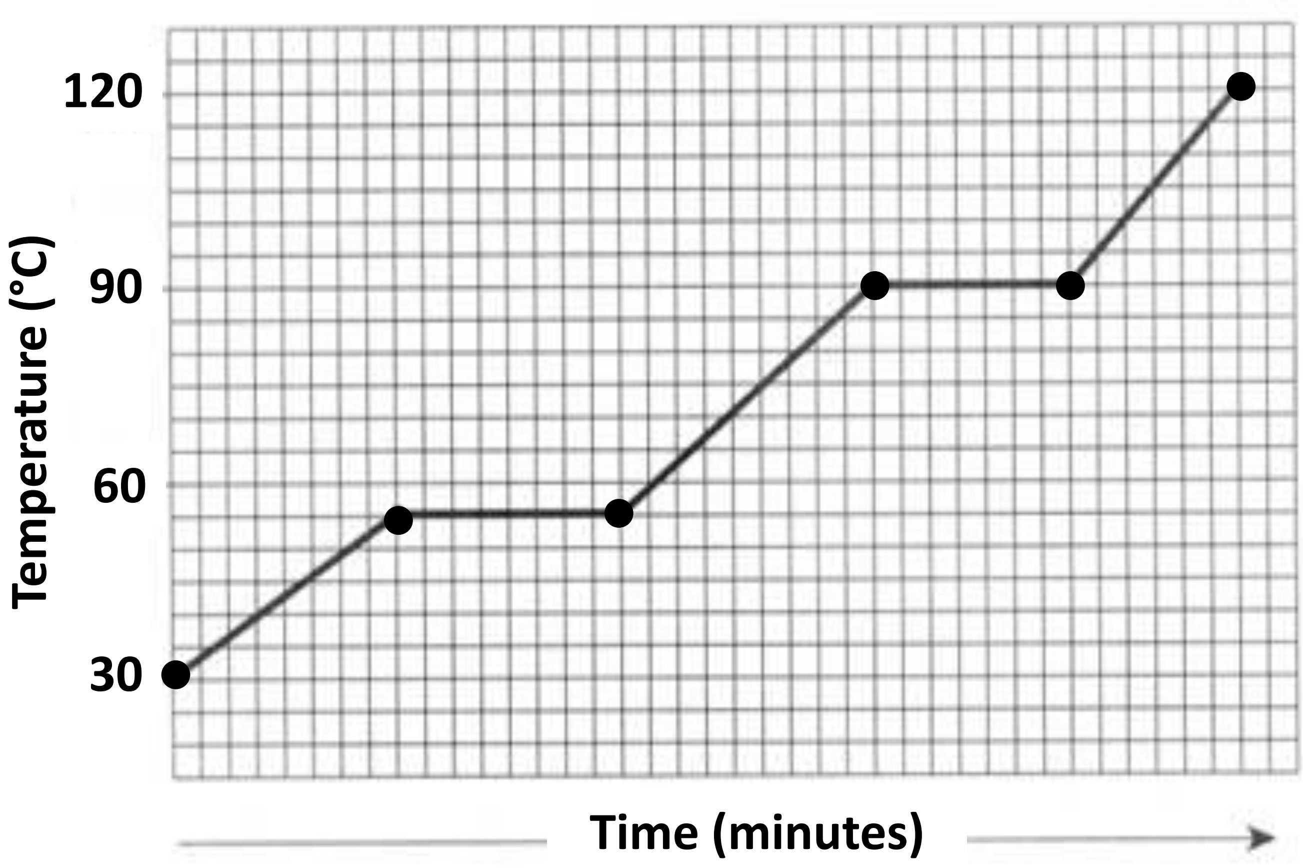
A. AB
B. AD
C. $\boxed{\text{BC}}$
D. BD



T16Q2: Level 1 (L.G. 3)

Consider the heating curve below for substance X. The boiling point of substance X is________.

A. 30°C
B. 60°C
C. 90°C
D. 120°C



T16Q2: Solution

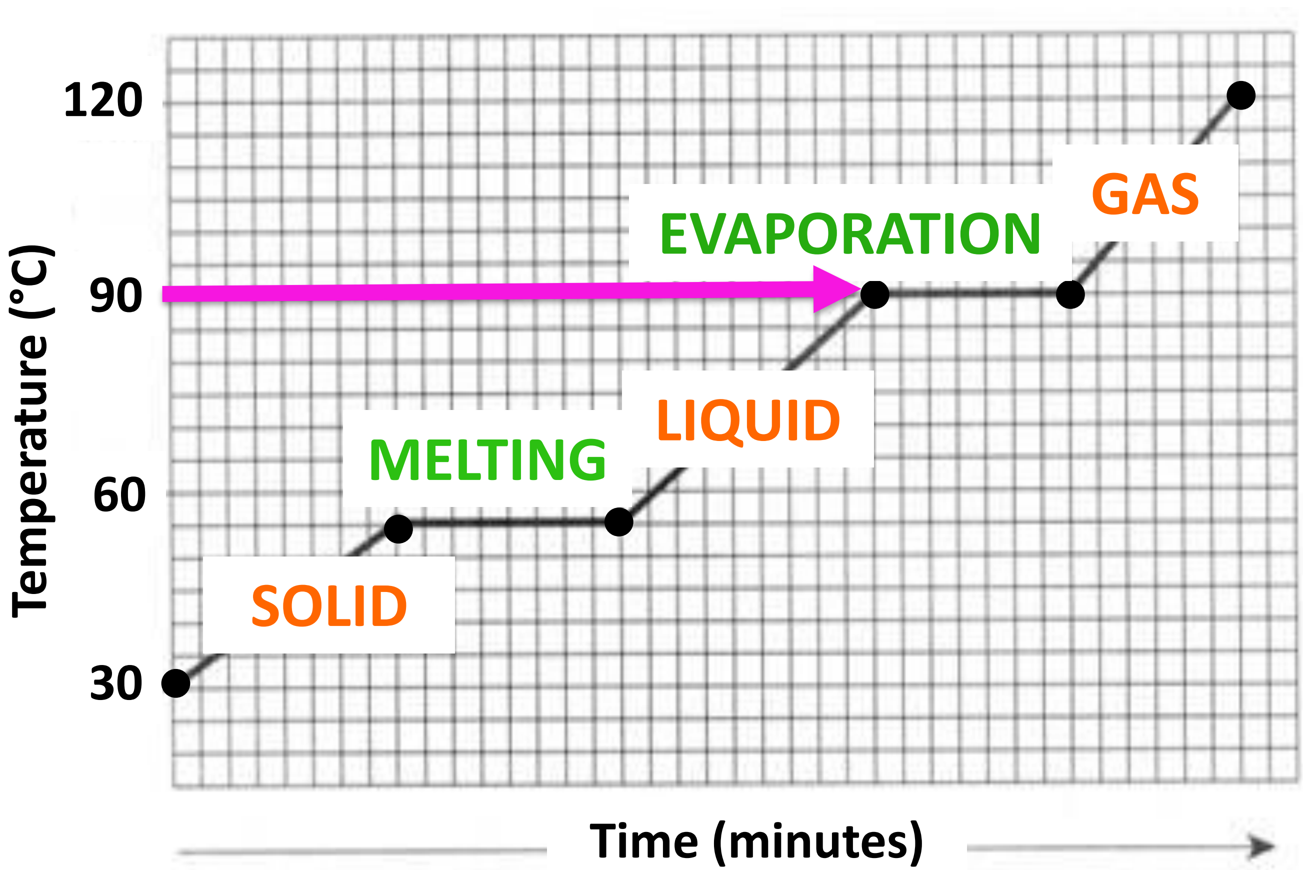
Consider the heating curve below for substance X. The boiling point of substance X is__________.

A. 30°C

B. 60°C

C. $\boxed{\text{90°C}}$

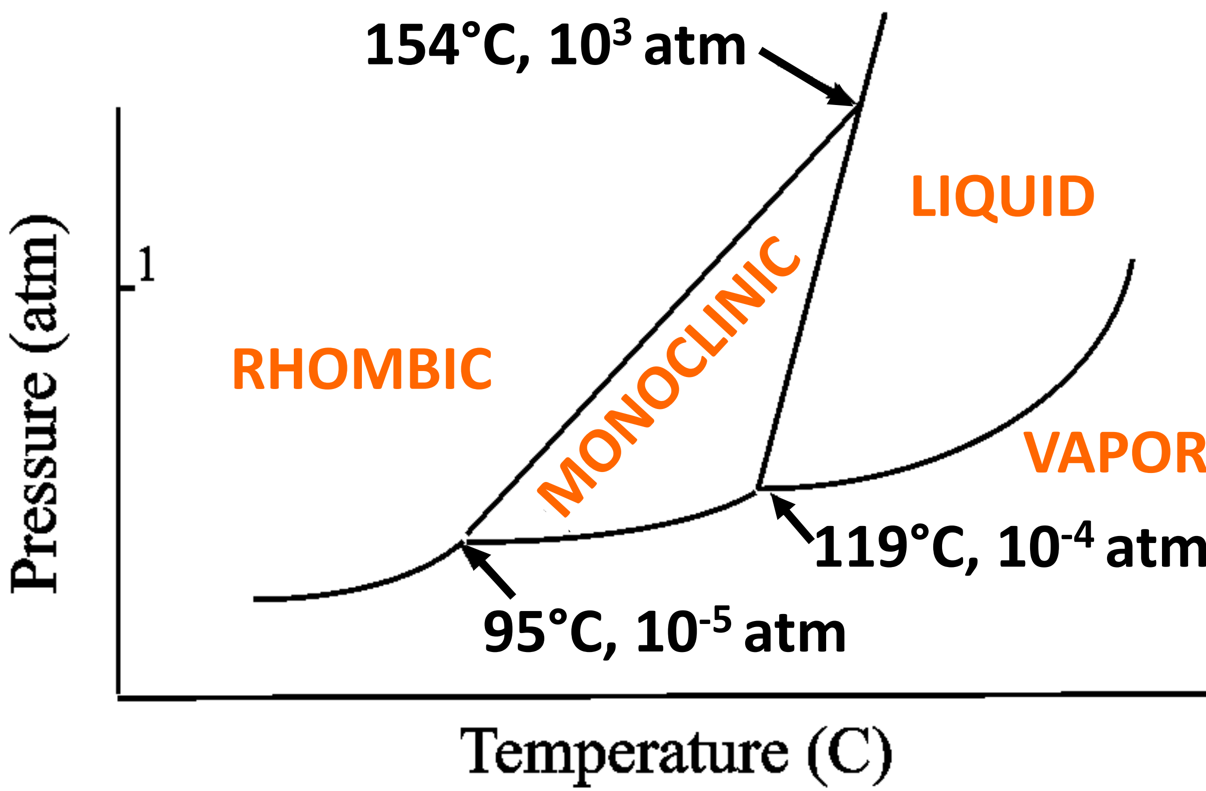
D. 120°C



T16Q3: Level 2 (L.G. 3)

Substances can have more than 3 phases. Sulfur exists in two solid phases – rhombic and monoclinic according to the phase diagram below. At which of the following temperatures are only the 2 solids in equilibrium?

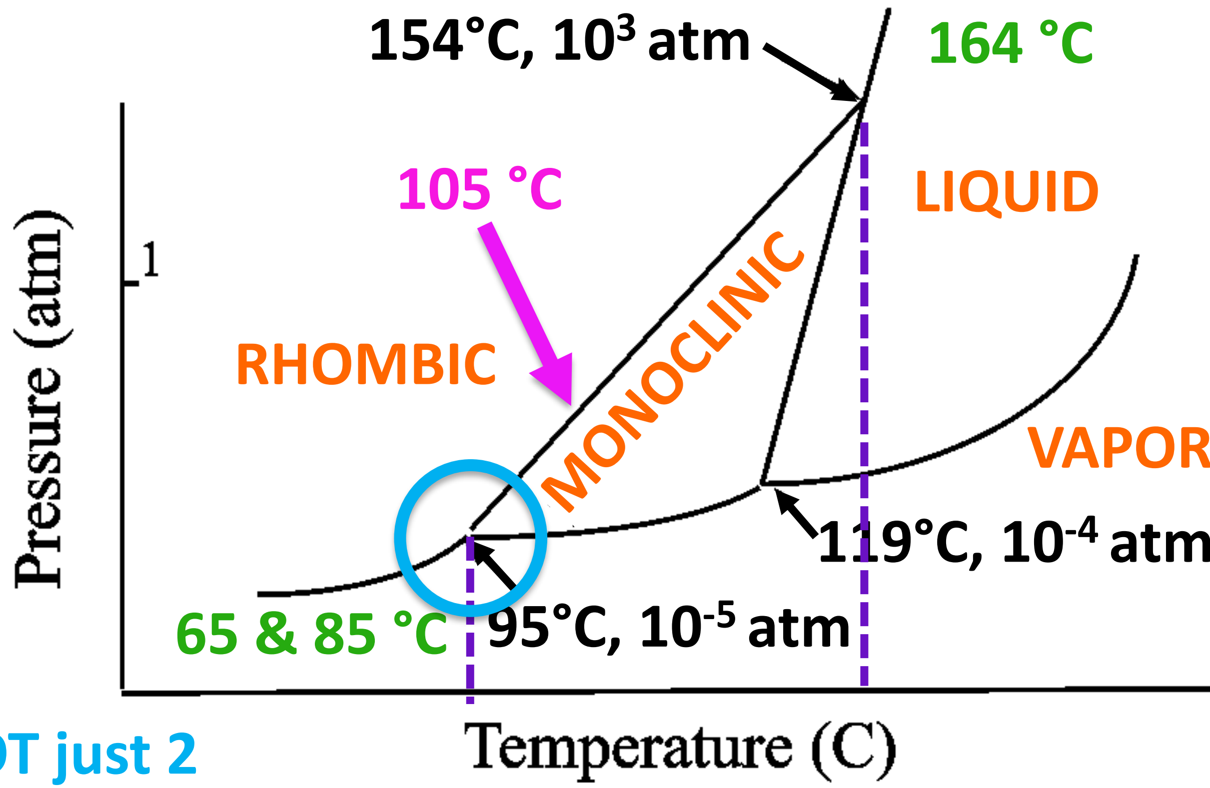
A. 65ºC
B. 85ºC
C. 95ºC
D. 105ºC
E. 164ºC



T16Q3: Solution

Substances can have more than 3 phases. Sulfur exists in two solid phases – rhombic and monoclinic according to the phase diagram below. At which of the following temperatures are only the 2 solids in equilibrium?

A. ~~65ºC~~
B. ~~85ºC~~
C. ~~95ºC~~
D. $\boxed{105ºC}$
E. ~~164ºC~~

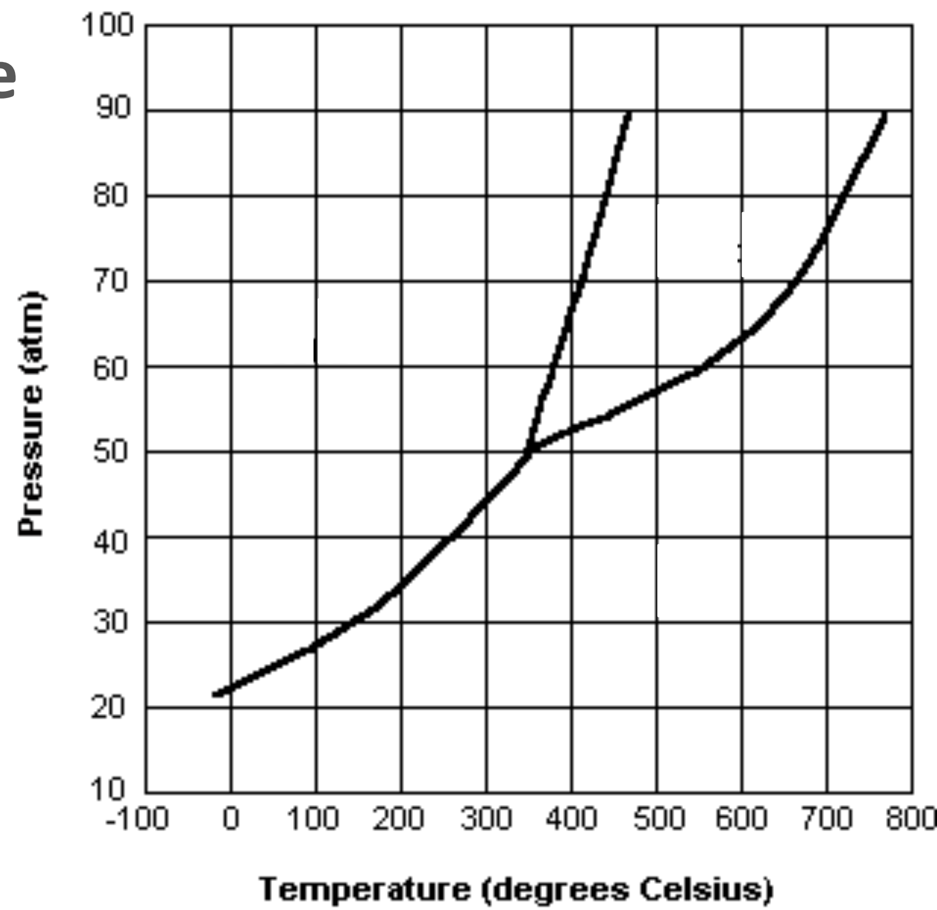


Triple point: 3 phases NOT just 2

T16Q4: Level 3 (L.G. 5)

Imagine you have a bottle of compound X at a constant pressure of 45 atm and a temperature of 100 °C. What will happen to compound X if you raise the temperature to 500 °C?

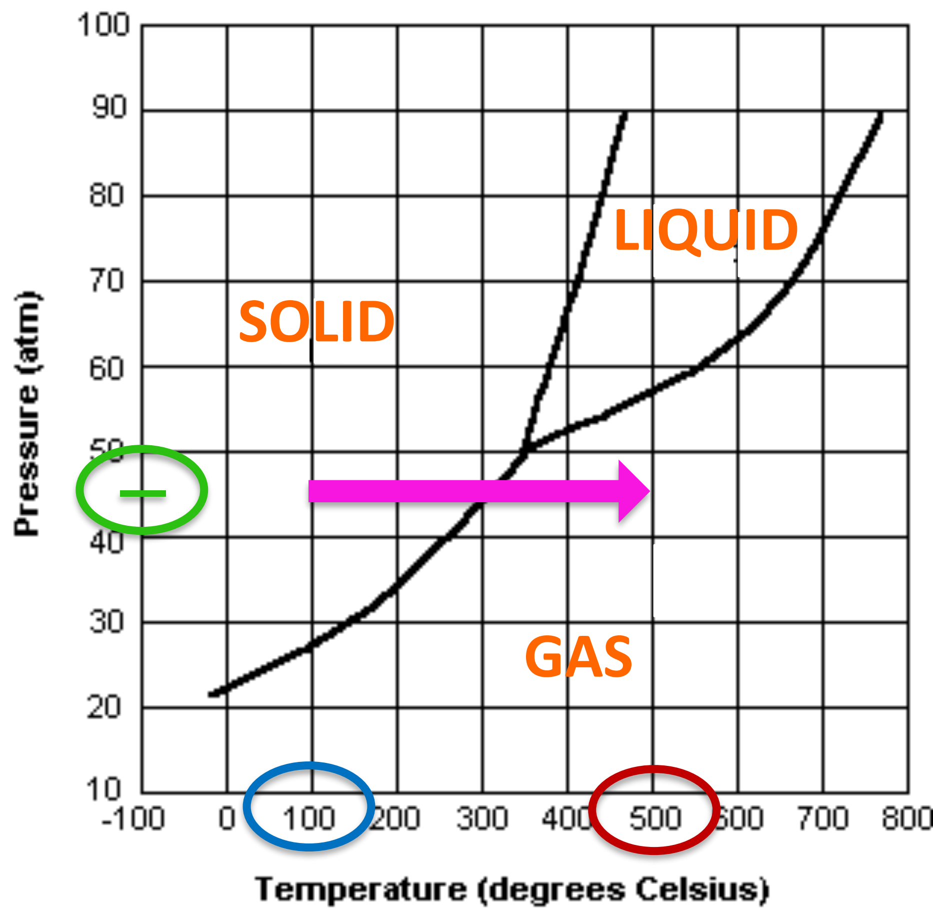
A. Compound X will evaporate
B. Compound X will sublime
C. Compound X will melt
D. Compound X will remain a solid



T16Q4: Solution

Imagine you have a bottle of compound X at a constant pressure of 45 atm and a temperature of 100 °C. What will happen to compound X if you raise the temperature to 500 °C?

A. Compound X will evaporate
B. Compound X will sublime
C. Compound X will melt
D. Compound X will remain a solid



The phase change from solid to gas is sublimation.

IMF Review

London Dispersion forces (LDFs) are the weakest IMF (one a one to one comparison) and occur in EVERY single molecule.

Dipole-Dipole (D-D) Interactions occur only in POLAR molecules and are stronger than LDFs (on a one to one comparison)

H -bonds are a special type of Dipole-Dipole Interaction. They are the strongest type of IMF (on a one to one comparison)

In order to form a H-bond, a molecule must have a hydrogen atom attached to one of the following:

O, N or F

As IMF get strong boiling point and enthalpy of vaporization (ΔH_{vap}) increases and Vapor pressure (P_{vap}) decreases

Some more questions for you to practice at home

T15Q9: Level 4 (L.G. 1)

When an unknown hydrate of Na_2CO_3 is heated until all the water is removed, it looses 54.3% of its mass. What was the formula of the hydrate before it was heated?

A. Na_2CO_3
B. $Na_2CO_3 \bullet 1H_2O$
C. $Na_2CO_3 \bullet 5H_2O$
D. $Na_2CO_3 \bullet 7H_2O$

T15Q9: Solution

When an unknown hydrate of Na_2CO_3 is heated until all the water is removed, it looses 54.3% of its mass. What was the formula of the hydrate before it was heated?

A. Na_2CO_3
B. $Na_2CO_3 \bullet 1H_2O$
C. $Na_2CO_3 \bullet 5H_2O$
D. $\boxed{Na_2CO_3 \bullet 7H_2O}$

T15Q9: Solution

When an unknown hydrate of Na_2CO_3 is heated until all the water is removed, it looses 54.3% of its mass. What was the formula of the hydrate before it was heated?

$Na_2CO_3 \bullet XH_2O$ What is X?

Species	Na_2CO_3	XH_2O
%	**100 - 54.3 = 45.7%**	**54.3 %**
Grams	**45.7**	**54.3**
Moles	45.7/(106.01 g/mol) **= 0.431 mol**	54.3/(18 g/mol) **= 3.01 mol**
Mole Ratio	0.431/0.431 **= 1**	3.01/0.431 **= 7**

$Na_2CO_3 \bullet 7H_2O$

T15Q9: Solution Alternative (no table)

When an unknown hydrate of Na_2CO_3 is heated until all the water is removed, it looses 54.3% of its mass. What was the formula of the hydrate before it was heated?

A. Na_2CO_3
B. $Na_2CO_3 \bullet 1H_2O$
C. $Na_2CO_3 \bullet 5H_2O$
D. $\boxed{Na_2CO_3 \bullet 7H_2O}$

$Na_2CO_3 \bullet XH_2O$ What is X?

Mass of XH_2O is 54.3%
Mass of Na_2CO_3 is (100 – 54.3) = 45.7%
$M_w(Na_2CO_3)$ = 106.01 g/mol
$M_w(H_2O)$ = 18.02 g/mol

45.7 % = 106.01 g/mol
100% = X

X = total mass
= 106.01g/mol x (100/45.7)
= 231.95 g/mol

Mass of XH_2O = total - Na_2CO_3 mass
= 231.95 – 106.01
= 125.96 g/mol

Mol of H_2O = mass/Mw
= 125.96/18.02
X = 6.99 = 7

T15Q12: Level 3 (L.G. 1)

Vanadinite (**$Pb_5(VO_4)_3Cl$**) and is one of the main industrial ores that are used for the extraction of elemental vanadium.
If you start with 1.21 kg of $Pb_5(VO_4)_3Cl$, what is the maximum number of grams of V that can be extracted from this ore.

A. **43.2 grams**
B. **130 grams**
C. **155 grams**
D. **173 grams**

T15Q12: Solution

Vanadinite (**$Pb_5(VO_4)_3Cl$**) and is one of the main industrial ores that are used for the extraction of elemental vanadium.
If you start with 1.21 kg of $Pb_5(VO_4)_3Cl$, what is the maximum number of grams of V that can be extracted from this ore.

A. 43.2 grams
B. $\boxed{\text{130 grams}}$
C. 155 grams
D. 173 grams

% V in $Pb_5(VO_4)_3Cl$:

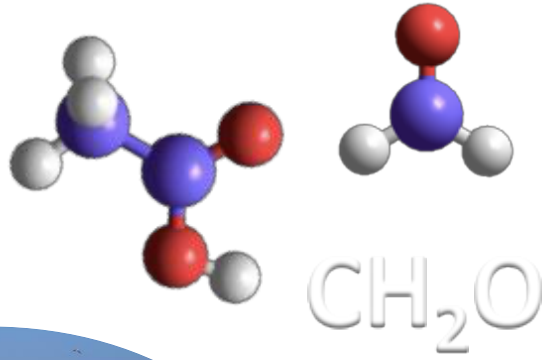
$$=[(\#V)(M_w V)/M_w Pb_5(VO_4)_3Cl] \times 100\%$$
$$= 3(50.94)/(1416.27 \text{ g/mol}) \times 100\%$$
$$= 10.79\%$$

Mass of V that can be extracted:

$$= (10.79/100) \times (1.21 \text{ kg}) * (1000\text{g}/1\text{kg})$$
$$= 130.5 \text{ g}$$

Topics 16&17

Intermolecular Forces & Gases



Peer Instruction
Clicker Session 18

IMF Review

London Dispersion forces (LDFs) are the weakest IMF (one a one to one comparison) and occur in EVERY single molecule.

Dipole-Dipole (D-D) Interactions occur only in POLAR molecules and are stronger than LDFs (on a one to one comparison)

H -bonds are a special type of Dipole-Dipole Interaction. They are the strongest type of IMF (on a one to one comparison)

In order to form a H-bond, a molecule must have a hydrogen atom attached to one of the following:

O, N or F

As IMF get strong boiling point and enthalpy of vaporization (ΔH_{vap}) increases and Vapor pressure (P_{vap}) decreases

T16Q1: Level 3 (L.G. 12)

How many of the following molecules exhibit H-bonds, how many exhibit dipole-dipole interactions and how many exhibit London Dispersion forces respectively?

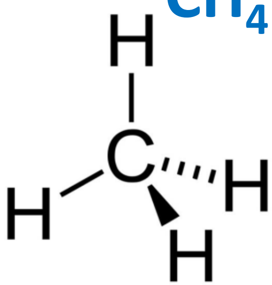
CH_4 **CH_3OH** **H_2S** **NH_3**

A. 1, 2 and 4
B. 2, 2 and 4
C. 2, 3 and 4
D. 2, 0 and 2
E. 1, 2 and 1

T16Q1: Solution

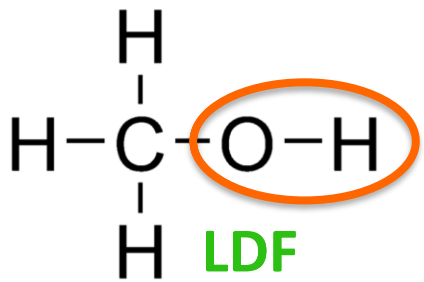
How many of the following molecules exhibit H-bonds, how many exhibit dipole-dipole interactions and how many exhibit London Dispersion forces respectively?

CH_4



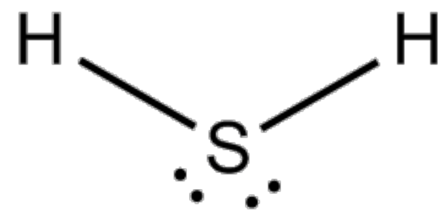
LDF

CH_3OH



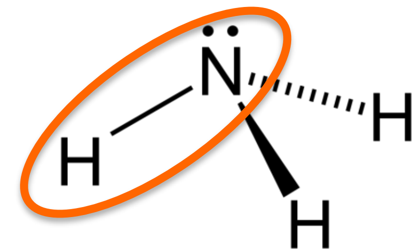
LDF
D-D
H-Bonds

H_2S



LDF
D-D

NH_3



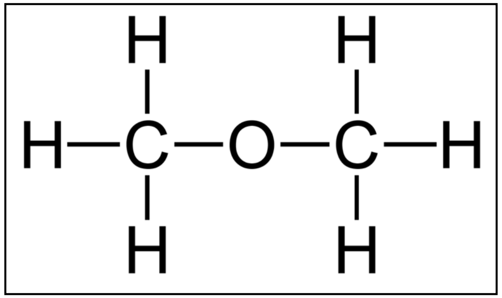
LDF
D-D
H-Bonds

A. 1, 2 and 4
B. 2, 2 and 4
C. 2, 3 and 4
D. 2, 0 and 2
E. 1, 2 and 1

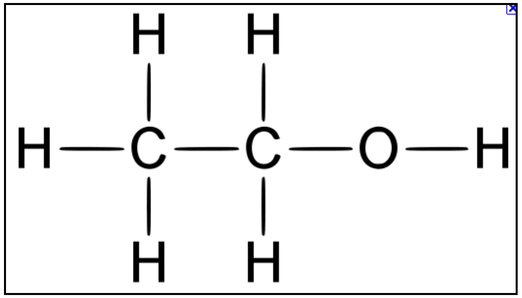
IMF are not mutually exclusive! Just because you have stronger forces like H-bonds, doesn't mean the D-D and LDFs go away

T16Q2: Level 2 (L.G. 12)

Which of the following has a higher boiling point and why?



Dimethyl ether (CH_3OCH_3)



Ethanol (CH_3CH_2OH)

A. **Dimethyl ether because it has LDF, dipole-dipole interactions and hydrogen bonds**

B. **Dimethyl ether because it has only LDF and dipole-dipole interactions**

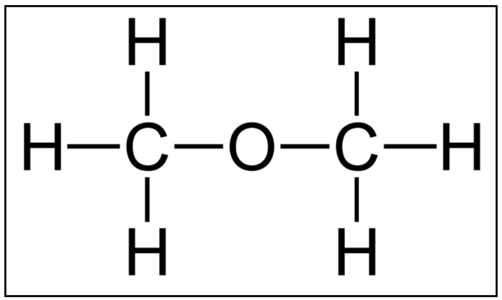
C. **Ethanol because it has LDF, dipole-dipole interactions and hydrogen bonds**

D. **Ethanol because it has only LDF and dipole-dipole interactions**

T16Q2: Solution

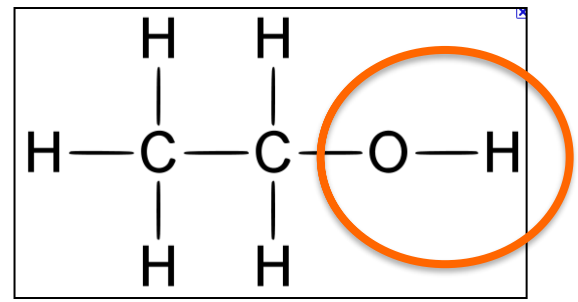
Which of the following has a higher boiling point and why?

POLAR



Dimethyl ether (CH_3OCH_3)

POLAR



Ethanol (CH_3CH_2OH)

A. **Dimethyl ether because it has LDF, dipole-dipole interactions and hydrogen bonds**

B. **Dimethyl ether because it has only LDF and dipole-dipole interactions**

As IMF's get stronger bp increases.

C. **Ethanol because it has LDF, dipole-dipole interactions and hydrogen bonds**

D. **Ethanol because it has only LDF and dipole-dipole interactions**

T16Q3: Level 2 (L.G. 12)

Based on the $\Delta H_{vaporization}$ values shown in the table below, which of the following compounds has the strongest intermolecular forces (IMF's)?

A. Argon
B. Benzene
C. Ethanol
D. Water
E. Methane

Substance	ΔH_{vap}
Argon (Ar)	6.3 kJ/mol
Benzene (C_6H_6)	31 kJ/mol
Ethanol (C_2H_5OH	39.3 kJ/mol
Methane (CH_4)	9.2 kJ/mol
Water (H_2O)	40.8 kJ/mol

T16Q3: Solution

Based on the $\Delta H_{vaporization}$ values shown in the table below, which of the following compounds has the strongest intermolecular forces (IMF's)?

A. Argon
B. Benzene
C. Ethanol
D. $\boxed{\text{Water}}$
E. Methane

Substance	ΔH_{vap}
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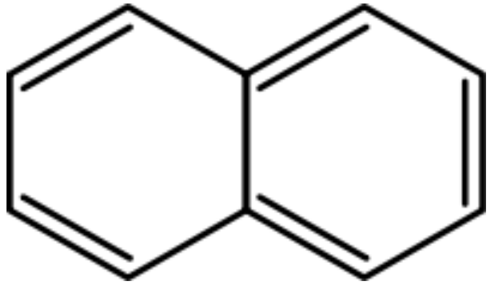
Ethanol (C_2H_5OH	39.3 kJ/mol
Methane (CH_4)	9.2 kJ/mol
Water (H_2O)	40.8 kJ/mol

ΔH_{vap} ➔ energy required to vaporize a substance
Higher ΔH_{vap} corresponds to more energy required to go from liquid to gas ➔ IMFs must be stronger

T16Q4: Level 3 (L.G. 12)

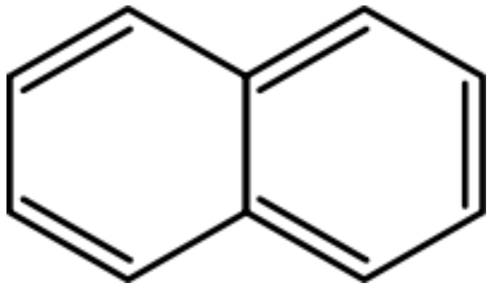
Napthalene ($C_{10}H_8$) is an organic molecule that has only LDF. How is it possible then that napthalene is a solid at room temperature, but water is a liquid?



A. Molecules with stronger IMF always have have higher boiling points.
B. Water molecules can form H-bonds so water must have stronger IMF than those of napthalene.
C. Napthalene is a large planar molecule and so its LDF's are stronger than the H-bond in water.
D. Molecules with stronger IMF are more likely to be solids at room temperature.

T16Q4: Solution

Napthalene ($C_{10}H_8$) is an organic molecule that has only LDF. How is it possible then that napthalene is a solid at room temperature, but water is a liquid?



A. Molecules with stronger IMF always have have higher boiling points.

B. Water molecules can form H-bonds so water must have stronger IMF than those of napthalene.

C. Napthalene is a large planar molecule and so its LDF's are stronger than the H-bond in water.

D. Molecules with stronger IMF are more likely to be solids at room temperature.

Napthalene is a large planar molecule with a flat surface that allows for two molecules to interact in many positions and at a very close range!

T16Q5: Level 4 (L.G. 12)

Consider the molecules: H_2O, CO_2, NH_3, CCl_4. The boiling points of these four molecules from lowest boiling point to highest boiling point are -78°C, -34°C, 76°C, 100°C. Place these molecules in order from highest boiling point to lowest boiling point.
(**HINT:** Both NH_3 and CO_2 are gases at room temperature.)

A. **H_2O, CCl_4, NH_3, CO_2**
B. **H_2O, NH_3, CCl_4, CO_2**
C. **NH_3, CO_2, CCl_4, H_2O**
D. **H_2O, CCl_4, CO_2, NH_3**

T16Q5: Solution

Consider the molecules: H_2O, CO_2, NH_3, CCl_4. The boiling points of these four molecules from lowest boiling point to highest boiling point are -78°C, -34°C, 76°C, 100°C. Place these molecules in order from highest boiling point to lowest boiling point.
(**HINT:** Both NH_3 and CO_2 are gases at room temperature.)

A. $\boxed{H_2O, CCl_4, NH_3, CO_2}$

~~**B.** H_2O, NH_3, CCl_4, CO_2~~

~~**C.** NH_3, CO_2, CCl_4, H_2O~~

~~**D.** H_2O, CCl_4, CO_2, NH_3~~

You know the bp of H_2O is 100 so you know H_2O must be first.

NH_3 and CO_2 are gases, so they must have weaker IMF than CCl_4 which is a liquid.

NH_3 is polar and forms hydrogen bonds, whereas CO_2 only has LDF.

T16Q6: Level 3 (L.G. 12)

Pure samples of which of the following compounds will exhibit hydrogen bonding?

I. CH_3OH II. CH_3NO_3 III. CH_3CN

A. **I only**
B. **I and II only**
C. **II and III only**
D. **I, II and III**

T16Q6: Solution

Pure samples of which of the following compounds will exhibit hydrogen bonding?

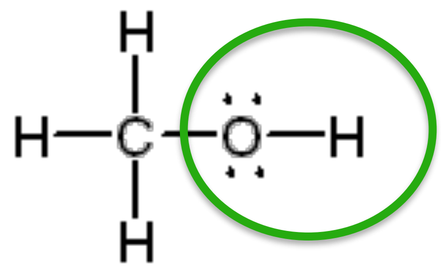
I. CH_3OH II. CH_3NO_3 III. CH_3CN

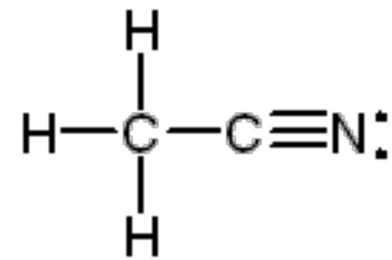
A. I only

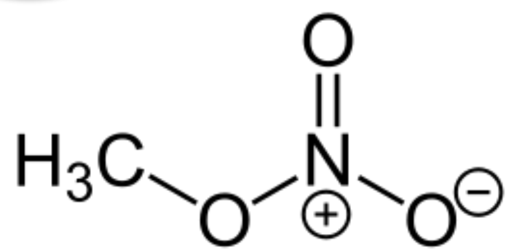
B. I and II only

C. II and III only

D. I, II and III







In order to form a hydrogen bond, a molecule must have a hydrogen attached to one of the following: O, N or F.

T16Q7: Level 2 (L.G. 12)

Which one of the following molecules is predicted to have the lowest boiling point?

A. H_2S
B. PH_3
C. HCl
D. SiH_4
E. H_2O

T16Q7: Solution

Which one of the following molecules is predicted to have the lowest boiling point?

A. H_2S
B. PH_3
C. HCl
D. $\boxed{SiH_4}$
E. H_2O

As BP increases IMF must get stronger.
SiH_4 is the only non-polar molecule thus it has the weakest IMFs (only LDFs).

Make sure you can draw all the Lewis structures and predict the polarity.

Topic 17 Learning Goals

As a student, I am able to:

1	list the ideal gas postulates and relate them to the motion of gas molecules
2	identify the four variables used to characterize a gas quantitatively (P, T, V and n)
3	describe pressure as an average Force/Area
4	recognize when the average force increases due to momentum changes or frequency changes
5	realize that the pressure of a gas is proportional to the mole number of the gas (at constant P,T,V) thus gas pressure can be used in place of mole in stoichiometry calculations.
6	assign the proper units to each of the variables: expressing P in atm, n in moles, T in Kelvin, and V in liters and use R = 0.0821 Latm/mol K
7	convert among units of V (milliliter, liter, cm^3); units of P (torr, atm, kPa); and units of T (C and K)
8	write down the ideal gas law and use algebra to rearrange PV=nRT to isolate each variable.
9	identify problems as single state and then set up the single state equation with one variable
10	identify problems as two state problems and then can find the variables that are changing and those that are not changing
11	modify the single state equation to explicitly solve for density, mass, or molar mass
12	solve the double state problem for an unknown and for relative changes in volume and pressure

Topic 17 Learning Goals

As a student, I am able to:

13	relate the speeds of the particles to their kinetic energy and use a graph to show that different particles have different energies at one temperature
14	remember and write down the relationship between PV and KE and between T and KE
15	use the PV and KE equations to relate speed and mass (and molar mass) to temperature
16	predict relative average speeds and relative diffusion rates of gaseous particles
17	predict relative speeds of effusion and diffusion

Topic 17 Material

Ideal vs Real Gases
Know the ideal gas postulates and differentiate between real and ideal
Ideal Gas Law calculations: PV= nRT
Use the idea gas law to solve for P, V, n or T – SINGLE state problems
Use the idea gas law to solve for P, V, n or T – DOUBLE state problems
Use the idea gas law to solve for molecular weight (g/mol) and molarity (n/V)
Kinetic Energy calculations: KE = (½)mV^2 and KE = (3/2)nRT
Relate KE, speed (rate of diffusion), mass and T to one another.

T17Q1: Level 1 (L.G. 1)

An ideal gas differs from a real gas in that the molecules of an ideal gas ___________.

A. **have a molecular weight of zero**
B. **have no kinetic energy**
C. **have no attraction for one another**
D. **have appreciable molecular volumes**

T17Q1: Solution

An ideal gas differs from a real gas in that the molecules of an ideal gas ___________.

A. **have a molecular weight of zero**
B. **have no kinetic energy**
C. **have no attraction for one another**
D. **have appreciable molecular volumes**

Ideal gas molecules:

1. **have no volume of their own**
2. **have perfectly elastic collisions and are in constant linear motion**
3. **experience no intermolecular forces acting between one another.**
4. **The KE of an ideal gas is directly proportional to its temperature measured in degrees K.**

T17Q2: Level 2 (L.G. 1)

At what values of temperature and pressure would real gases behave more like ideal gases?

A. **Low pressure and low temperature**
B. **High pressure and high temperature**
C. **Low pressure and high temperature**
D. **High pressure and low temperature**

T17Q2: Solution

At what values of temperature and pressure would real gases behave more like ideal gases?

A. **Low pressure and low temperature**
B. **High pressure and high temperature**
C. **Low pressure and high temperature**
D. **High pressure and low temperature**

T17Q2: Solution

At what values of temperature and pressure would real gases behave more like ideal gases?

1. Gas molecules have no volume

Low pressure implies a larger volume of the entire gaseous system
Size of the individual gas particle becomes negligible compared to the whole

2. Gas molecules have perfectly elastic collisions

3. Gas molecules have no intermolecular forces

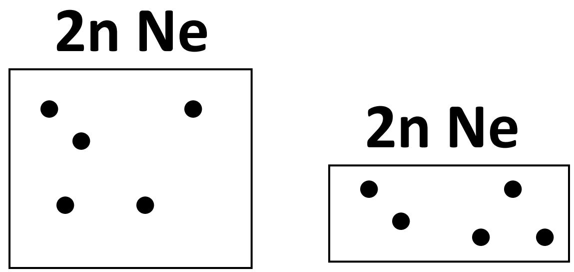
$$\left(KE = 1/2mV_o^2\right)$$

High temperature implies lots of kinetic energy (KE → internal movement)
Particles are not in contact with one another for long enough to allow an energy exchange → elastic collisions (no energy transfer)
No IMF exist because particles are moving too quickly to interact

T17Q3: Level 2 (L.G. 3)

$V_A = 2L$

$T_A = 127°C$



$V_B = 1L$

$T_B = -73°C$

Which container experiences a greater **pressure**?

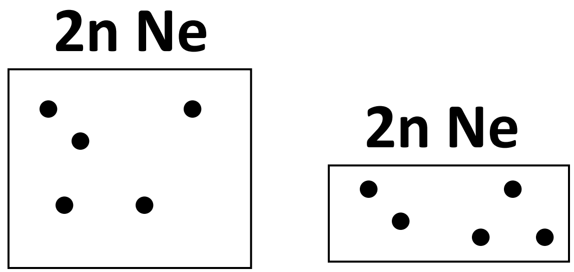
A. The pressure is the same

B. Container A

C. Container B

T17Q3: Solution

V_A = 2L
T_A = 127°C



V_B = 1L
T_B = -73°C

Which container experiences a greater **pressure**?

A. The pressure is the same
B. Container A
C. Container B

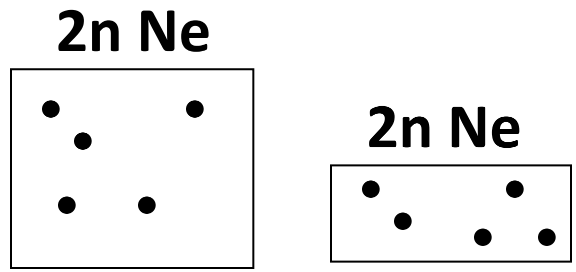
PV = nRT

$P \propto n \propto T \propto 1/V$

Temperature of A is at twice that of B (400 K vs 200 K).
Volume of A is twice that of B (2L vs 1L).
Same amount of gas in both containers
The 2 containers are at the same pressure!

T17Q4: Level 2 (L.G. 3)

$V_A = 2L$
$T_A = 127°C$



$V_B = 1L$
$T_B = -73°C$

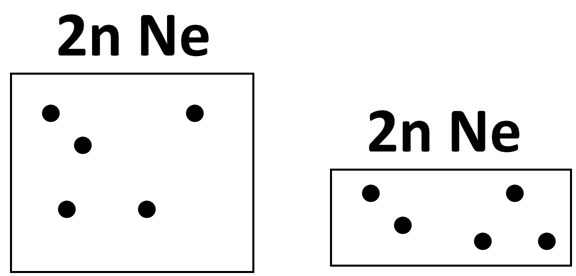
The **average force** with which a neon atom collides with the walls of its container is greater in______?

A. The ave. force is the same
B. Container A
C. Container B

T17Q4: Solution

$V_A = 2L$

$T_A = 127°C$



$V_B = 1L$

$T_B = -73°C$

The **average force** with which a neon atom collides with the walls of its container is greater in______?

A. The ave. force is the same

B. Container A

C. Container B

Temp is higher in A

→ The neon molecules are moving FASTER in A

NEON: Same mass

→Hit HARDER in A

PRESSURE → COLLISIONS

1. **Frequency of collisions**
2. **Magnitude of the force of collisions**

What does “hardness” mean?

“Hardness” is directly related to the force with which a particle collides with the wall

Generalization 1:

When 2 particles travelling at the same speed collide with a wall, the heavier particle will always collide harder → larger force

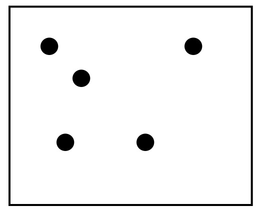
Generalization 2:

When 2 particles of the same mass collide with a wall, the particle travelling at a faster speed will collide harder → larger force

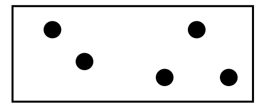
T17Q5: Level 3

$V_A = 2L$
$T_A = 127°C$

2n Ne



2n Ne



$V_B = 1L$
$T_B = -73°C$

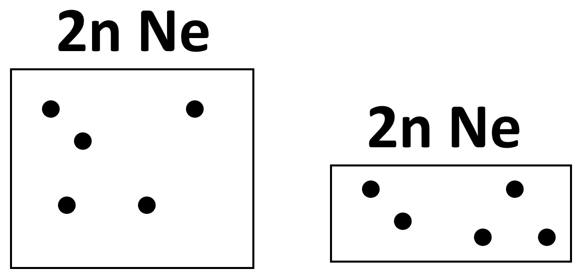
The frequency with which the neon atoms collide with the walls of their container is greater in which container?

A. **The frequency of collisions is the same**
B. **Container A**
C. **Container B**

T17Q5: Solution

(400 K) $V_A = 2L$

$T_A = 127°C$



$V_B = 1L$ (200 K)

$T_B = -73°C$

The frequency with which the neon atoms collide with the walls of their container is greater in which container?

A. The frequency of collisions is the same

B. Container A

C. Container B

$PV = nRT$

$T_A = 2T_B$ and $V_A = 2V_B$ and $n_A = n_B$

The 2 containers are at the same pressure!

The neon molecules are moving faster in A $T_A > T_B$ ➔ $KE_A > KE_B$

So, particles in A hit harder.

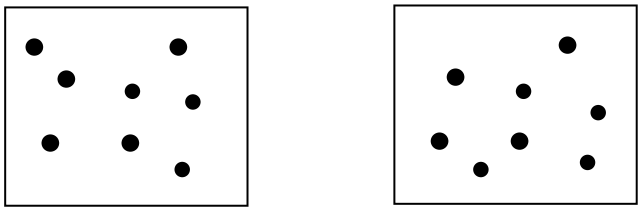
If $P_A = P_B$, but they hit harder in container A, they must be hitting more often in container B.

T17Q6: Level 3

Consider the two 1L containers of diatomic gas shown to the right. If both containers are at STP, which molecules will collide with the walls of the container with a greater force?

Container A
2mol O_2

Container B
2mol N_2

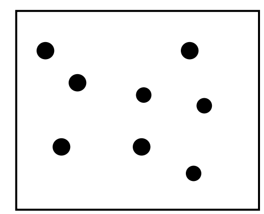


A. **The molecules in container A**
B. **The molecules in container B**
C. **They will hit with the same force**
D. **Not enough information**

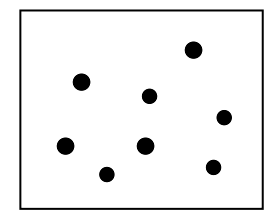
T17Q6: Solution

Consider the two 1L containers of diatomic gas shown to the right. If both containers are at STP, which molecules will collide with the walls of the container with a greater force?

Container A
2mol O_2



Container B
2mol N_2



A. The molecules in container A
B. The molecules in container B
C. They will hit with the same force
D. Not enough information

T is the same:

$$KE_{O_2} = KE_{N_2}$$

$$\tfrac{1}{2}(m_{O_2}v^2_{O_2}) = \tfrac{1}{2}(m_{N_2}v^2_{N_2})$$

N_2 → lighter → faster → hits more often
O_2 → heavier → slower → hits less often

Pressure is also the same: about # collisions & force of collisions

O_2 molecules hit less often → must be hitting harder!

IDEAL GAS LAW: SINGLE STATE

$$PV = nRT$$

$$P \propto n \propto T \propto 1/V$$

$$P = \frac{nRT}{V} \quad V = \frac{nRT}{P} \quad T = \frac{PV}{nR} \quad n = \frac{PV}{RT}$$

You must be able to isolate ANY of the 4 variables!

T17Q7: Level 2 (L.G. 9)

Calculate the number of moles of helium in a helium balloon that is inflated to a total pressure of 120 kPa with a volume of 1.3 L at 22°C (**NOTE: 1 atm = 101,325 Pa)**

A. **0.045 moles**
B. **0.064 moles**
C. **0.853 moles**
D. **15.62 moles**

T17Q7: Solution

Calculate the number of moles of helium in a helium balloon that is inflated to a total pressure of 120 kPa with a volume of 1.3 L at 22°C (**NOTE: 1 atm = 101,325 Pa)**

A. **0.045 moles**

$\boxed{\textbf{B.} \quad \textbf{0.064 moles}}$

C. **0.853 moles**

D. **15.62 moles**

SINGLE STATE PROBLEM

PV = nRT

T: Kelvin

P: atm

R = 0.082 L-atm/mol-K

P = 120 kPa x (1000 Pa/1 Kpa) x (1 atm/101325 Pa) = 1.18 atm

T = 22 + 273 = 295 K

$$n = PV/RT = \frac{(1.18)\text{atm}\ (1.3\ \text{L})}{(0.082\ \text{L-atm/mol-K})\ (295)\text{K}} = 0.064\ \text{moles}$$

Some more questions for you to practice at home

T16Q14: Level 2 (L.G. 13)

State why the normal melting point of ICl(27.2°C) is so much higher than that of Br_2 (-7.2°C). The molecules of both substances have the same number of electrons.

A. **The ICl molecule undergoes hydrogen bonding**
B. **The Cl atom in the ICl molecule is more polarizable than the Br atom in the Br_2 molecule.**
C. **ICl molecule is polar**
D. **Iodine in ICl is more electronegative than bromine in Br_2**

T16Q14: Solution

State why the normal melting point of ICl(27.2°C) is so much higher than that of Br_2 (-7.2°C). The molecules of both substances have the same number of electrons.

A. The ICl molecule undergoes hydrogen bonding

B. The Cl atom in the ICl molecule is more polarizable than the Br atom in the Br_2 molecule.

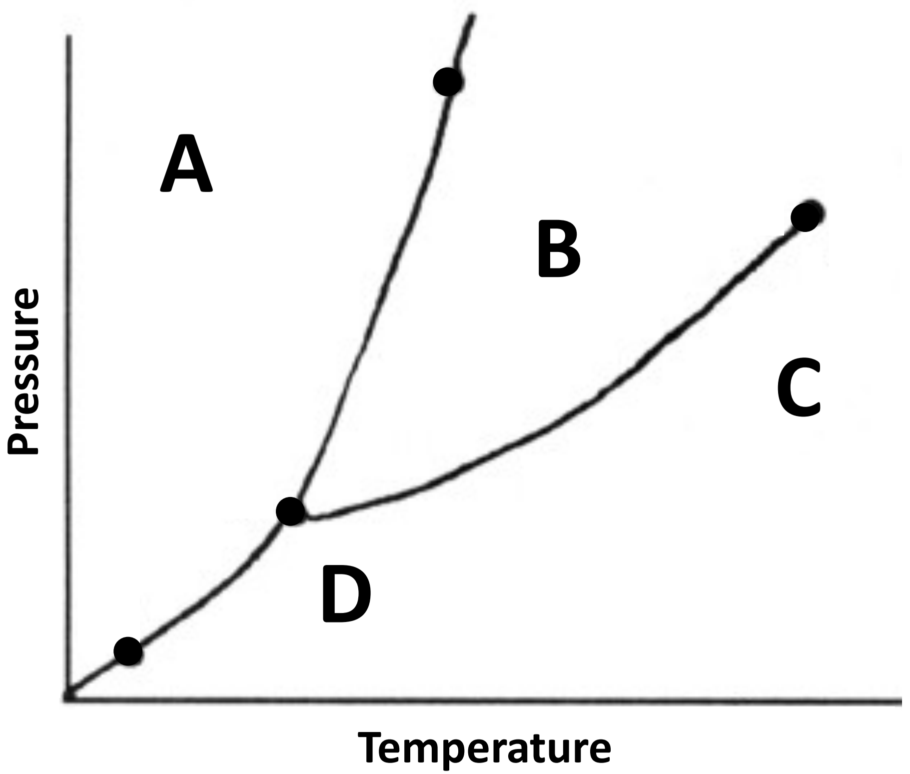
C. ICl molecule is polar

D. Iodine in ICl is more electronegative than bromine in Br_2

T16Q16: Level 1 (L.G. 3)

Which region on the phase diagram below corresponds to the solid phase?

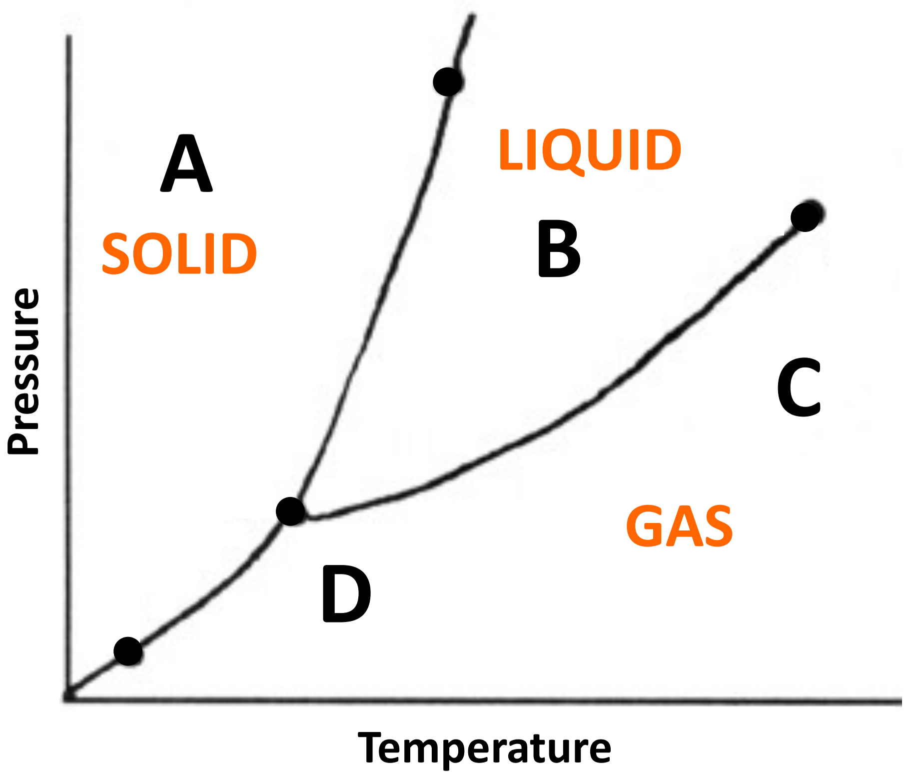
A. A
B. B
C. C
D. D



T16Q16: Solution

Which region on the phase diagram below corresponds to the solid phase?

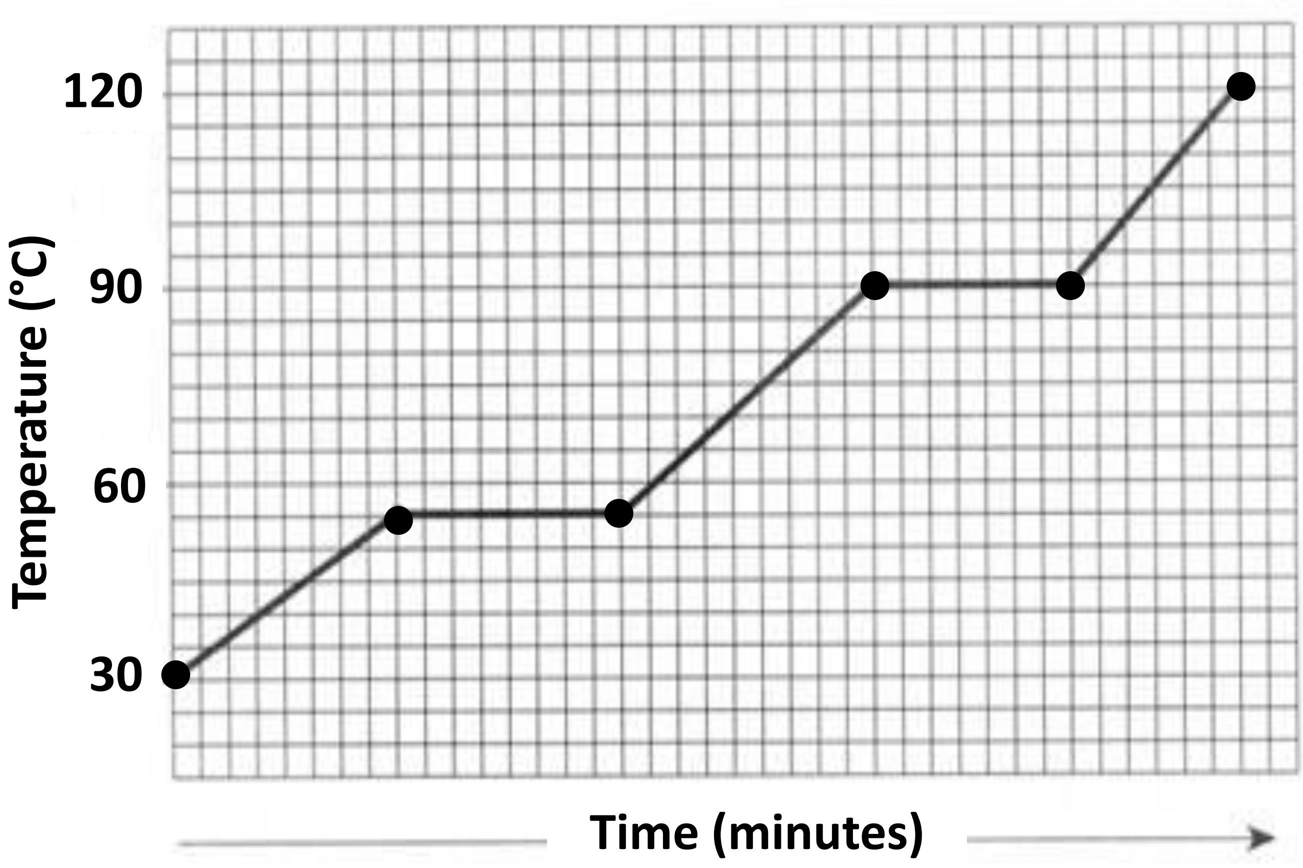
A. A
B. B
C. C
D. D



T16Q17: Level 1 (L.G. 3)

Consider the heating curve below for substance X. At 75°C substance X exists as a ________________.

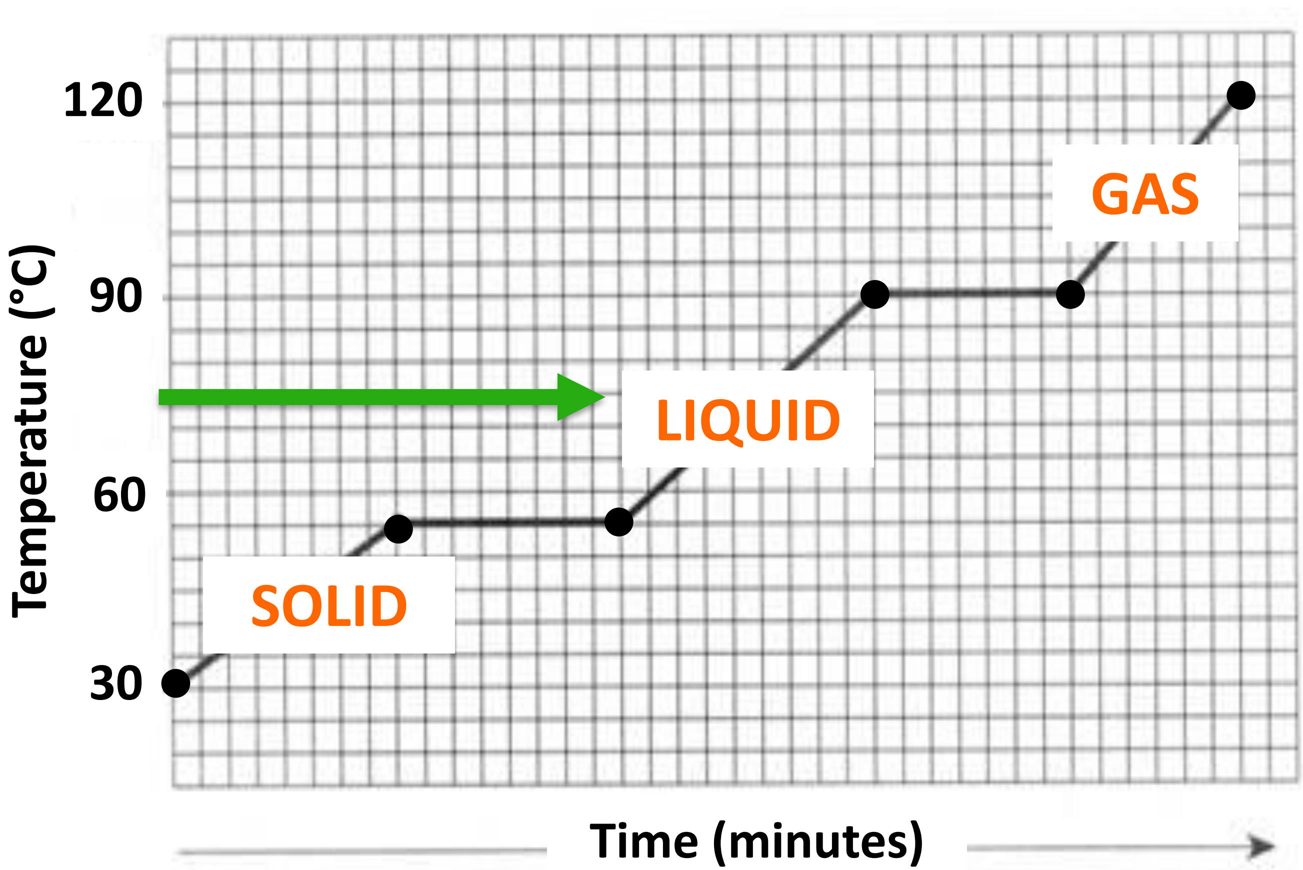
A. Solid
B. liquid
C. gas
D. liquid and solid
E. liquid and gas



T16Q17: Solution

Consider the heating curve below for substance X. At 75°C substance X exists as a ________________.

A. Solid
B. liquid
C. gas
D. liquid and solid
E. liquid and gas



T16Q13: Level 2 (L.G. 11)

Which of the following statements is **not** characteristic of a hydrogen bond?

A. **The other atom involved in the hydrogen bond (not the hydrogen atom) must be a very electronegative atom that is attached to another hydrogen atom.**
B. **The other atom involved in the hydrogen bond (not the hydrogen atom) always possesses at least one lone pair of electrons.**
C. **The hydrogen atom involved must be covalently bonded to a very electronegative atom.**
D. **Hydrogen bonds are typically weaker than ionic or covalent bonds.**

T16Q13: Solution

Which of the following statements is **not** characteristic of a hydrogen bond?

Electronegative atom in H-bond: N, O or F

A. **The other atom involved in the hydrogen bond (not the hydrogen atom) must be a very electronegative atom that is attached to another hydrogen atom.**
B. **The other atom involved in the hydrogen bond (not the hydrogen atom) always possesses at least one lone pair of electrons.**
C. **The hydrogen atom involved must be covalently bonded to a very electronegative atom.**
D. **Hydrogen bonds are typically weaker than ionic or covalent bonds.**

T16Q14: Level 2 (L.G. 12)

The boiling point of water is about 200°C higher than one would predict from the boiling points of hydrogen sulfide and hydrogen selenide. One may explain this apparent anomaly by which of the following?

A. **The H-O covalent bond is much stronger than the H-S and H-Se bonds**
B. **Water has the lowest molecular weight**
C. **The intermolecular attractive forces are much greater in water than in hydrogen sulfide and hydrogen selenide.**
D. **Water is less polar than hydrogen sulfide and hydrogen selenide.**

T16Q14: Solution

The boiling point of water is about 200°C higher than one would predict from the boiling points of hydrogen sulfide and hydrogen selenide. One may explain this apparent anomaly by which of the following?

A. **The H-O covalent bond is much stronger than the H-S and H-Se bonds**

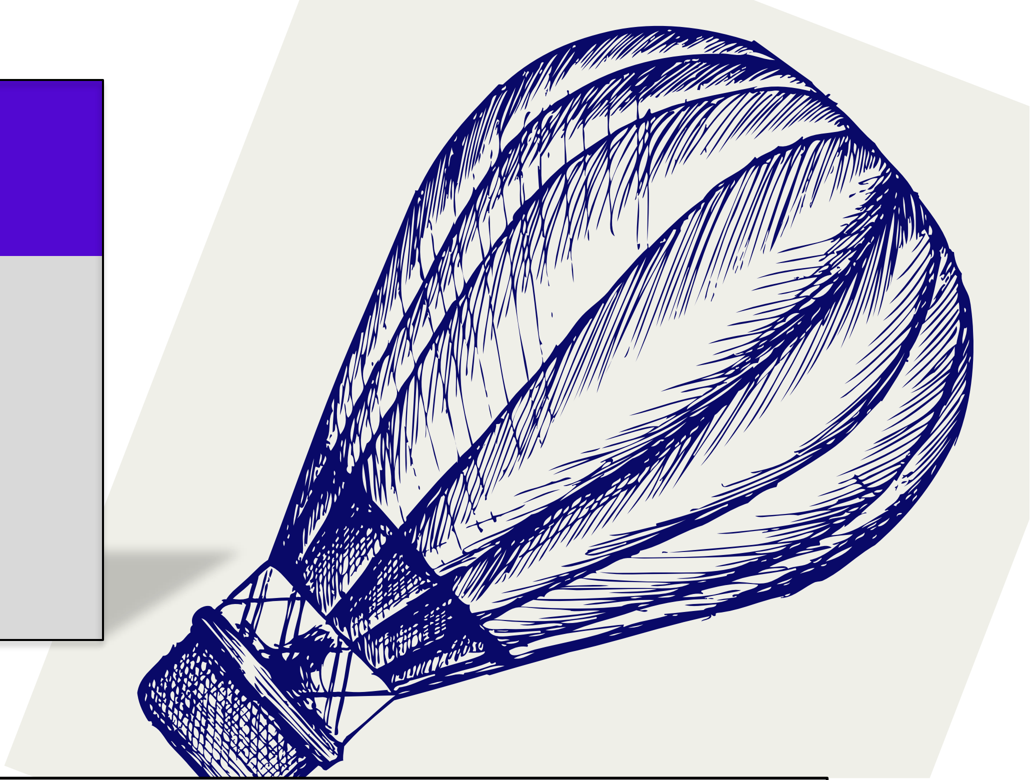
B. **Water has the lowest molecular weight**

C. **The intermolecular attractive forces are much greater in water than in hydrogen sulfide and hydrogen selenide.** **Hydrogen bonding!**

D. **Water is less polar than hydrogen sulfide and hydrogen selenide.**

Topic 17B

Gases



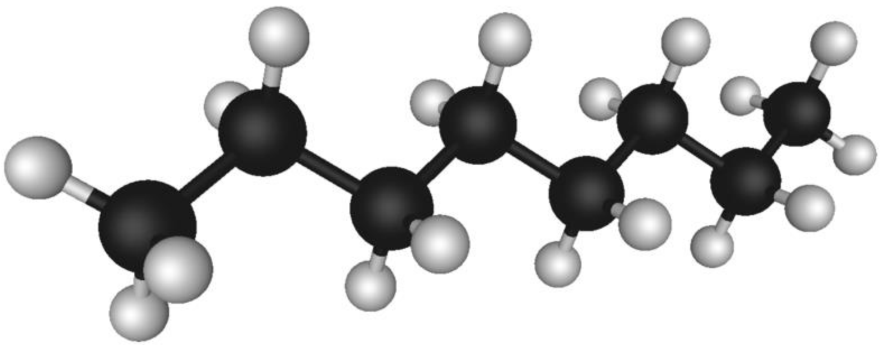
Peer Instruction
Clicker Session 19

8 pt Challenge

Octane (C_8H_{18}) is a straight chain of carbon atoms with no dipole moment and a boiling point of 125°C. Water has a dipole moment, can hydrogen bond and has a boiling point of 100°C. The difference between these two boiling points can best be rationalized by:

A. **Intermolecular forces between molecules with dipole moments are greater than between molecules with no dipole moment**
B. **Hydrogen bonding is a strong intermolecular force**
C. **London dispersion forces are weak but there are many LDFs in octane so the net IMF in C_8H_{18} is greater than the net IMF in H_2O**
D. **London dispersion forces are strong and so the boiling point of octane is greater than the boiling point of water**
E. **There is no trend, this is a magical mystery of science**

Q0: Solution



of carbon atoms with no dipole
25°C. Water has a dipole moment,
ling point of 100°C. The difference
s can best be rationalized by:

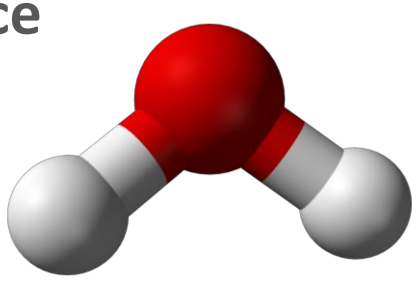
A. **Intermolecular forces between molecules with dipole moments are greater than between molecules with no dipole moment**

B. **Hydrogen bonding is a strong intermolecular force**

C. **London dispersion forces are weak but there are many LDFs in octane so the net IMF in C_8H_{18} is greater than the net IMF in H_2O**

D. **London dispersion forces are strong and so the boiling point of octane is greater than the boiling point of water**

E. **There is no trend, this is a magical mystery of science**



Topic 17 Material

Ideal vs Real Gases
Know the ideal gas postulates and differentiate between real and ideal
Ideal Gas Law calculations: PV= nRT
Use the idea gas law to solve for P, V, n or T – SINGLE state problems
Use the idea gas law to solve for P, V, n or T – DOUBLE state problems
Use the idea gas law to solve for molecular weight (g/mol) and molarity (n/V)
Kinetic Energy calculations: KE = (½)mV^2 and KE = (3/2)nRT
Relate KE, speed (rate of diffusion), mass and T to one another.

IDEAL GAS LAW: SINGLE STATE

$$PV = nRT$$

$$P \propto n \propto T \propto 1/V$$

$$P = \frac{nRT}{V} \qquad V = \frac{nRT}{P} \qquad T = \frac{PV}{nR} \qquad n = \frac{PV}{RT}$$

You must be able to isolate ANY of the 4 variables!

T17Q1: Level 2 (L.G. 9)

Calculate the volume of helium in a 2-mole helium balloon that floats up into the atmosphere and is left inflated to a total pressure of 1.5 atm at a temperature of -73 deg C.

A. **37.9 L**
B. **22.1 L**
C. **7.98 L**
D. **0.045 L**

T17Q1: Solution

Calculate the volume of helium in a 2-mole helium balloon that floats up into the atmosphere and is left inflated to a total pressure of 1.5 atm at a temperature of -73 deg C.

A. 37.9 L

B. 22.1 L

C. 7.98 L

D. 0.045 L

SINGLE STATE PROBLEM

PV = nRT

T: Kelvin

P: atm

R = 0.082 L-atm/mol-K

$$V = nRT/P = \frac{2.0 \text{ mol} \times (0.082 \text{ L-atm/mol-K}) \times (-73 + 273)\text{K}}{1.5 \text{ atm}}$$

$$= 22.1 \text{ L}$$

T17Q2: Level 2+ (L.G. 9)

How many moles of nitrogen will be needed to react with 1.5 L of H_2 gas measured at 20°C and 0.95 atm?

A. **0.059 moles**
B. **0.020 moles**
C. **0.18 moles**
D. **0.87 moles**

T17Q2: Solution

SINGLE STATE PROBLEM
CHEM RXN

How many moles of nitrogen will be needed to react with 1.5 L of H_2 gas measured at 20°C and 0.95 atm?

A. 0.059 moles
B. 0.020 moles
C. 0.18 moles
D. 0.87 moles

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

PV = nRT

Find moles of H_2 first

$$n = PV/RT$$

$$= \frac{(0.95\text{atm})\,(1.5\text{ L})}{(0.082\text{ L-atm/mol-K})\,(20 + 273)\text{K}}$$

$$= 0.059 \text{ moles } H_2$$

$$0.059 \text{ mol } H_2 \times (1 \text{ mol } N_2/3 \text{ mol } H_2) = 0.020 \text{ moles } N_2$$

T17Q3: Level 3 (L.G. 9)

What volume of O_2 is needed to completely react with 28.0 g NH_3 at 24°C and 0.950 atm to form NO and water?

A. **4.26 L**
B. **42.3 L**
C. **46.1 L**
D. **52.8 L**

T17Q3: Solution

SINGLE STATE PROBLEM
CHEM RXN

What volume of O_2 is needed to completely react with 28.0 g NH_3 at 24°C and 0.950 atm to form NO and water?

A. 4.26 L
B. 42.3 L
C. 46.1 L
D. 52.8 L

$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$

Find moles of O_2 using Stoich calcs first

28 g x (1 mol/(17 g/mol) = 1.65 moles NH_3

1.65 moles NH_3 x (5 mol O_2/4 mol NH_3)
= 2.06 moles O_2

Now find volume of O_2

PV = nRT

V = nRT/P

= (2.06 moles)(0.082 L-atm/mol-K)(24 + 273 K)/0.95 atm

= 52.8 L

T17Q4: Level 3 (L.G. 11)

Determine the molecular weight of a gas that has a density of 5.75 g/L at STP.

A. **3.90 g/mol**
B. **129 g/mol**
C. **141 g/mol**
D. **578 g/mol**

T17Q4: Solution

SINGLE STATE Molecular Weight

Determine the molecular weight of a gas that has a density of 5.75 g/L at STP.

STP: 1atm, 273K

A. 3.90 g/mol
B. 129 g/mol
C. 141 g/mol
D. 578 g/mol

$$PV = nRT$$

$$n = m/M_w$$

$$PV = RT(m/M_w)$$

$$M_w = RTm/PV$$

$$M_w = (RT/P)(m/V)$$

Density = mass/Vol

$$M_w = [(RT)/P](\text{Density})$$

$$M_w = [(0.082\ \text{L-atm/mol-K})(273\ \text{K})/(1\ \text{atm})](5.75\ \text{g/L})$$

$$= 129\ \text{g/mol}$$

T17Q5: Level 3 (L.G. 11)

Determine the density of a sample of unknown gas with a molar mass of 129 g/mol at STP.

A. **0.174 g/L**
B. **5.76 g/L**
C. **8.64 g/L**
D. **576 g/L**

T17Q5: Solution

Determine the density of a sample of unknown gas with a molar mass of 129 g/mol at STP.

A. 0.174 g/L
B. 5.76 g/L
C. 8.64 g/L
D. 576 g/L

STP: 1atm, 273K

$$PV = nRT$$

$n = m/M_w$

$$PV = RT(m/M_w)$$

Density = mass/Vol

$$P = (RT/M_w)\boxed{(m/V)}$$

$$P = (RT/M_w)(\text{density})$$

$$\text{Density} = PM_w/RT$$

$$\text{Density} = (1)(129)\,/(0.082)(273)$$

$$= 5.76\ \text{g/L}$$

T17Q6: Level 2 (L.G. 10)

Consider a sealed sample of gas at 33.0°C, 744 mm Hg, and 450 mL. If the pressure is decreased to 725 mm Hg and the temperature is raised to 66.0°C, what is the new volume of the gas?

A. **512 mL**
B. **124 mL**
C. **417 mL**
D. **483 mL**

CHANGE in the conditions: Double State Problem

Double State Problems:

$$P_1V_1 = n_1RT_1 \qquad P_2V_2 = n_2RT_2$$

$$\frac{P_1V_1}{P_2V_2} = \frac{\cancel{n_1}\cancel{R}T_1}{\cancel{n_2}\cancel{R}T_2}$$

R is a constant ALWAYS cancels

What is the relevant equation for a Sealed container?

n constant (sealed → closed container)

$$\frac{P_1V_1}{P_2V_2} = \frac{T_1}{T_2}$$

Double State Problems:

$$P_1V_1 = n_1RT_1 \qquad P_2V_2 = n_2RT_2$$

$$\frac{P_1\cancel{V}_1}{P_2\cancel{V}_2} = \frac{n_1\cancel{R}T_1}{n_2\cancel{R}T_2}$$

R is a constant ALWAYS cancels

What is the relevant equation for a Rigid container?

V constant (Rigid → No change in the shape)

$$\frac{P_1}{P_2} = \frac{n_1T_1}{n_2T_2}$$

Double State Problems:

$$P_1V_1 = n_1RT_1 \qquad P_2V_2 = n_2RT_2$$

$$\frac{P_1\cancel{V_1}}{P_2\cancel{V_2}} = \frac{\cancel{n_1}\cancel{R}T_1}{\cancel{n_2}\cancel{R}T_2}$$

R is a constant ALWAYS cancels

What is the relevant equation for the Sealed Rigid container?

n constant (closed container)

V constant (rigid container)

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

T17Q6: Level 2 (L.G. 10)

Consider a sealed sample of gas at 33.0°C, 744 mm Hg, and 450 mL. If the pressure is decreased to 725 mm Hg and the temperature is raised to 66.0°C, what is the new volume of the gas?

A. **512 mL**
B. **124 mL**
C. **417 mL**
D. **483 mL**

CHANGE in the conditions: Double State Problem

T17Q6: Solution

Consider a sealed sample of gas at 33.0°C, 744 mm Hg, and 450 mL. If the pressure is decreased to 725 mm Hg and the temperature is raised to 66.0°C, what is the new volume of the gas?

A. 512 mL
B. 124 mL
C. 417 mL
D. 483 mL

DOUBLE STATE PROBLEM

PV = nRT

$$\frac{P_iV_i}{\cancel{n_i}T_i}$$

R is a constant so it is not included!

T must be in Kelvin

$$V_f = [(P_iV_i)/(P_f)] \times (T_f/T_i)$$

$$= [(744)(450)/(725)] \times [(273+66)/(273+33)]$$

$$= 511.58 \text{ mL}$$

Units cancel so can keep mm Hg. T must be in K!!

T17Q7: Level 3 (L.G. 10)

A 1.9 mol sample of gas in a rigid flask at 21°C and 697 mm Hg is opened to the atmosphere and more gas is added to the flask. The pressure after the addition of gas is 795 mm Hg and the temperature is 26°C. How many moles of gas have been added to the container?

A. 0.23
B. 1.63
C. 1.75
D. 2.13
E. 2.9

T17Q7: Solution

A 1.9 mol sample of gas in a rigid flask at 21°C and 697 mm Hg is opened to the atmosphere and more gas is added to the flask. The pressure after the addition of gas is 795 mm Hg and the temperature is 26°C. How many moles of gas have been added to the container?

A. 0.23
B. 1.63
C. 1.75
D. 2.13
E. 2.9

$$\frac{P_i \cancel{V_i}}{P_f \cancel{V_f}} = \frac{n_i T_i}{n_f T_f}$$

DOUBLE STATE PROBLEM

$$n_f = [(n_i T_i)/(T_f)] \times (P_f/P_i)$$

$$= [(1.9)(21+273)/(26+273)] \times [(795)/(697)]$$

$$= 2.13 \text{ moles at the end}$$

Moles added = $n_f - n_i$ = 2.13 - 1.9 = 0.23 moles

Kinetic Energy (KE)

$KE = 1/2 M_w v_{rms}^2$ & $KE = (3/2)RT$

$1/2 M_w v_{rms}^2 = (3/2)RT$

$v_{rms}^2 = 3RT/M_w$

$$v_{rms} = \sqrt{\frac{3RT}{M_w}}$$

$V \ \alpha \ T$

$V \ \alpha \ 1/M_w$

For double state problems:

$$\frac{v_1}{v_2} = \sqrt{\frac{3RT_1 / Mw_1}{3RT_2 / Mw_2}}$$

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

$$\frac{v_1}{v_2} = \sqrt{\frac{Mw_2}{Mw_1}}$$

For double state problems:

$$\frac{KE_1 = (3/2)RT_1}{KE_2 = (3/2)RT_2}$$

$$\frac{KE_i}{KE_f} = \frac{T_i}{T_f}$$

T17Q8: Level 3 (L.G. 9)

Which of the following samples contains molecules with the greatest average kinetic energy?

A. **1.0 moles of N_2 at 580 K**
B. **1.0 moles of CO at 140 K**
C. **1.0 moles of N_2O at 298 K**
D. **1.0 moles of CO_2 at 440 K**

T17Q8: Solution

Which of the following samples contains molecules with the greatest average kinetic energy?

A. $\boxed{\text{1.0 moles of } N_2 \text{ at 580 K}}$
B. 1.0 moles of CO at 140 K
C. 1.0 moles of N_2O at 298 K
D. 1.0 moles of CO_2 at 440 K

KE is based only on the temperature of the gas
The higher the T the higher the KE

T17Q9: Level 1 (L.G. 15)

Consider 1L gaseous samples of He (4amu), Ne (20amu), and Ar (40amu). If each sample is at STP (273K, 1 atm). Which gas will have the highest molar kinetic energy?

- **A.** **He**
- **B.** **Ne**
- **C.** **Ar**
- **D.** **They all have the same energy**

T17Q9: Solution

Consider 1L gaseous samples of He (4amu), Ne (20amu), and Ar (40amu). If each sample is at STP (273K, 1 atm). Which gas will have the highest molar kinetic energy?

A. He
B. Ne
C. Ar
D. They all have the same energy

KE = 3/2RT

The KE of a gas = the **internal energy** of the system

All at the same temperature so all have the same KE

T17Q10: Level 3 (L.G. 14)

If the temperature of a gas is raised from 100 °C to 200 °C, the average kinetic energy of the gas will ____.

A. **increase by a factor of 2**
B. **increase by a factor of 1.27**
C. **increase by a factor of 100**
D. **decrease by a factor of 2**
E. **decrease by a factor of 100**

T17Q10: Solution

If the temperature of a gas is raised from 100 °C to 200 °C, the average kinetic energy of the gas will _____.

A. increase by a factor of 2
B. increase by a factor of 1.27
C. increase by a factor of 100
D. decrease by a factor of 2
E. decrease by a factor of 100

KE = 3/2RT

R is a constant
3/2 is a constant

DOUBLE STATE PROBLEM

$$\frac{KE_i}{KE_f} = \frac{T_i}{T_f}$$

$$KE_f = KE_i \boxed{(T_f/T_i)}$$

FACTOR

$$(T_f/T_i) = (473)/(373)$$
$$= 1.27$$

T increases so KE increases

Topic 18

Solutions

Peer Instruction
Clicker Session 20

8 pt Challenge

Consider the following gas reaction that runs with 100% yield: $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

How many liters of oxygen gas do you need to completely react with 54 L of carbon monoxide gas at STP?

A. 22 L
B. 27 L
C. 54 L
D. 81 L
E. 108 L

Q0: Solution

Consider the following gas reaction that runs with 100% yield: 1 $2CO(g) + O_2(g) \rightarrow 2CO_2(g)$

How many liters of oxygen gas do you need to completely react with 54 L of carbon monoxide gas at STP?

A. 22 L
B. 27 L
C. 54 L
D. 81 L
E. 108 L

2 $\boxed{PV = nRT}$ $n = PV/RT$

$= 1\text{ atm}(54\text{ L})/(0.082(273\text{K}))$

$= 2.41$ moles

3 2.41 moles CO x (1 mol O_2/2 mol CO)

$= 1.21$ moles O_2

4 $\boxed{PV = nRT}$ $V = nRT/P$

$= 1.21\text{ moles}(0.082)(273\text{K})/1\text{ atm}$

$= 27$ L

8 pt Challenge again

Consider a rigid tank containing both HF and HBr gases. If this tank develops a leak, what is the ratio of the rate of effusion of HF to the rate of effusion of HBr at constant T?

A. **4.04**
B. **0.247**
C. **2.01**
D. **0.497**

Q0b: Solution

Consider a rigid tank containing both HF and HBr gases. If this tank develops a leak, what is the ratio of the rate of effusion of HF to the rate of effusion of HBr at constant T?

A. 4.04
B. 0.247
C. 2.01
D. 0.497

Effusion is about speed

$$KE = \tfrac{1}{2}mv^2$$

T is constant so KE is the same

DOUBLE STATE PROBLEM

$$KE_{HF} = KE_{HBr}$$

$$Mw_{HF}v_{HF}^2 = Mw_{HBr}v_{HBr}^2$$

$$\boxed{\frac{v_{HF}}{v_{HBr}} = \sqrt{\frac{Mw_{HBr}}{Mw_{HF}}}} = \sqrt{\frac{81}{20}} = 2.01$$

Kinetic Energy (KE)

$KE = 1/2 M_w v_{rms}^2$ & $KE = (3/2)RT$

$$1/2 M_w v_{rms}^2 = (3/2)RT$$

$$v_{rms}^2 = 3RT/M_w$$

$$\boxed{v_{rms} = \sqrt{\frac{3RT}{M_w}}}$$

For double state problems:

$$\frac{v_1}{v_2} = \sqrt{\frac{T_1}{T_2}}$$

$$\frac{v_1}{v_2} = \sqrt{\frac{3RT_1 / Mw_1}{3RT_2 / Mw_2}}$$

$$\frac{v_1}{v_2} = \sqrt{\frac{Mw_2}{Mw_1}}$$

Topic 18 Learning Goals

As a student, I am able to:

1	draw particles diagrams for dissolving an ionic solid in water or for dissolving a polar covalent compound in water
2	identify the solute and the solvent in a solution
3	use molarity formula to compute mass, moles, volume, or molarity
4	use the dilution formula to compute molarity and volume after dilution
5	identify and name the 3 types of reactions: • Combustion • Synthesis and decomposition • Precipitation/dissolution
6	predict products of combustion reactions from known oxides
7	predict products of synthesis and decomposition reactions
8	predict products of precipitation reactions using solubility rules
9	write molecular and net ionic equations for precipitation and dissolution reactions
10	demonstrate knowledge of nomenclature rules, types of reactions, and predicting products of reactions by <u>performing stoichiometric calculations</u> for reactions containing solids, liquids, gases, or solutions

Topic 18 Material

Solutions and Solubility Rules
Use the solubility rules to predict solubility and write net ionic equation
Solution Calculations (M = m/L)
Convert between moles, mass and molarity and use the dilution formula
Stoichiometry (in all its glory – finally)
Do stoichiometry calculations that integrate both gases and solutions

T18Q1: Level 1 (L.G. 3)

To make a 0.500 M solution, one could take 0.500 moles of solute and add _____________.

A. **1.00 L of solvent.**
B. **1.00 kg of solvent.**
C. **enough solvent to make 1.00 L of solution.**
D. **enough solvent to make 1.00 kg of solution.**

T18Q1: Solution

To make a 0.500 M solution, one could take 0.500 moles of solute and add _____________.

A. **1.00 L of solvent.**

B. **1.00 kg of solvent.**

C. **enough solvent to make 1.00 L of solution.**

D. **enough solvent to make 1.00 kg of solution.**

$$M = \frac{\text{moles of solute}}{\text{volume of solution (L)}}$$

T18Q2: Level 1 (L.G. 3)

A 500 g sample of potassium phosphate (K_3PO_4) is dissolved in 1.50 L of solution. What is the molarity of the solution?

A. **0.283 M**
B. **0.424 M**
C. **1.57 M**
D. **2.35 M**
E. **333 M**

T18Q2: Solution

A 500 g sample of potassium phosphate (K_3PO_4) is dissolved in 1.50 L of solution. What is the molarity of the solution?

- **A.** **0.283 M**
- **B.** **0.424 M**
- **C.** **1.57 M**
- **D.** **2.35 M**
- **E.** **333 M**

Find the Mw of the solute

↓

Find the moles of solute

↓

M = moles/Liter

$$M = \frac{\text{moles of solute}}{\text{volume of solution (L)}}$$

500 g / (212 g/mol) = 2.36 moles

$$\frac{2.36 \text{ moles}}{1.50 \text{ L}} = 1.57 \text{ M}$$

T18Q3: Level 2 (L.G. 3)

What is the concentration of nitrate ions in a 0.125 M $Mg(NO_3)_2$ solution?

A. **0.125 M**
B. **0.0625 M**
C. **0.375 M**
D. **0.250 M**

T18Q3: Solution

What is the concentration of nitrate ions in a 0.125 M $Mg(NO_3)_2$ solution?

A. 0.125 M
B. 0.0625 M
C. 0.375 M
D. 0.250 M

$Mg(NO_3)_2$

1 Mg^{2+} and 2 $(NO_3)^{-1}$

1 :2 mole ratio so the concentration of nitrate ions is double the concentration of magnesium nitrate:

$0.125\ M\ Mg(NO_3)_2 \times (2\ NO_3^{-1} / 1\ Mg(NO_3)_2) = 0.250\ M$

Think of an equation: $1Mg(NO_3)_2 \rightarrow 1Mg + 2(NO_3)^{-1}$

T18Q4: Level 3 (L.G. 4)

Imagine that you go into the lab and take 22 g of sodium sulfate and dissolve it in enough water to make 150 mL of solution. You now take 30 mL of this stock solution and add it to enough water to make a 0.68 M solution. How much water do you need to add to the 30 mL solution?

A. **155 mL**
B. **45.6 mL**
C. **30.0 mL**
D. **15.6 mL**

T18Q4: Solution

Imagine that you go into the lab and take 22 g of sodium sulfate and dissolve it in enough water to make 150 mL of solution. You now take 30 mL of this stock solution and add it to enough water to make a 0.68 M solution. How much water do you need to add to the 30 mL solution?

Na_2SO_4

A. 155 mL
B. 45.6 mL
C. 30.0 mL
D. 15.6 mL

Find stock M firstc

22 g /(142.04 g/mol)
= 0.155 moles

$$M = \frac{0.155 \text{ moles}}{0.150 \text{ L}} = 1.03 \text{ M}$$

$M_1V_1 = M_2V_2$

Now find the new Volume

$(1.03 \text{ M})(0.030 \text{ L}) = (0.68\text{M})(V_2)$

$V_2 = (1.03 \text{ M})(0.030 \text{ L})/(0.68 \text{ M}) = 0.0456 \text{ L}$

Volume to be added: 45.6 mL - 30 mL = 15.6 mL

T18Q5: Level 3 (L.G. 4)

A student prepared a stock solution by dissolving 10.0 g of KOH in enough water to make 150. mL of solution. She then took 15.0 mL of the stock solution and diluted it with enough water to make water to make 65.0 mL of a final solution. What is the concentration of KOH for the final solution?

A. **0.274 M**
B. **0.356 M**
C. **2.74 M**
D. **3.65 M**

T18Q5: Solution

A student prepared a stock solution by dissolving 10.0 g of KOH in enough water to make 150. mL of solution. She then took 15.0 mL of the stock solution and diluted it with enough water to make water to make 65.0 mL of a final solution. What is the concentration of KOH for the final solution?

A. 0.274 M
B. 0.356 M
C. 2.74 M
D. 3.65 M

10 g x (1 mol / 56.1 g/mol) = 0.178 moles

$$M = \frac{\text{moles of solute}}{\text{volume of solution (L)}}$$

$$\frac{0.178 \text{ moles}}{0.150 \text{ L}} = 1.19 \text{ M}$$

$$M_1V_1 = M_2V_2$$

$$(1.19 \text{ M})(0.015 \text{ L}) = (M_2)(0.065 \text{ L})$$

$$M_2 = (1.19 \text{ M})(0.015 \text{ L})/(0.065 \text{ L})$$

$$= 0.274 \text{ M}$$

Solubility rules (will be given on exam)

1. **Nitrate (NO_3^{-1}) and acetate ($C_2H_3O_2^{-1}$) salts are soluble.**
2. **Alkali metal (Group 1A) salts and NH_4^+ are soluble.**
3. **F^-, S^{2-}, CO_3^{2-}, CrO_4^{2-}, PO_4^{3-} salts are insoluble, except for those containing Group 1A cations.**
4. **Cl^{-1}, Br^{-1}, and I^{-1} salts are soluble (except when combined with Ag^+, Hg_2^{2+}, Pb^{2+}).**
5. **Sulfate salts are soluble (except when combined with Ag^+, Hg_2^{2+}, Pb^{2+}, Ca^{2+}, Sr^{2+} and Ba^{2+}).**
6. **OH^{-1} salts are insoluble (except for those containing Group 1A cations and NH_4^+ which are soluble and those containing Ca^{2+}, Sr^{2+} and Ba^{2+} which are slightly soluble).**

T18Q6: Level 2 (L.G. 8)

What precipitate is most likely formed from a solution containing Ba^{+2}, Na^{+1}, OH^{-1}, and CO_3^{-2}?

A. **NaOH**
B. **$BaCO_3$**
C. **Na_2CO_3**
D. **$Ba(OH)_2$**

T18Q6: Solution

What precipitate is most likely formed from a solution containing Ba^{+2}, Na^{+1}, OH^{-1}, and CO_3^{-2}?

A. NaOH → **Soluble, bc Na is a group 1 metal**

B. $\boxed{BaCO_3}$

C. Na_2CO_3 → **Soluble, bc Na is a group 1 metal**

D. $Ba(OH)_2$ → **Slightly soluble, bc OH & Ba^{2+}**

2. Alkali metal (Group 1A) salts and NH_4^+ are soluble.

3. F^-, S^{2-}, CO_3^{2-}, CrO_4^{2-}, PO_4^{3-} salts are insoluble, except for those containing Group 1A cations.

6. OH salts are insoluble (except for those containing Group 1A cations and NH_4^+ which are soluble and those containing Ca^{2+}, Sr^{2+} and Ba^{2+} which are slightly soluble).

T18Q7: Level 3 (L.G. 8)

How many of the following compounds are **soluble** in water?

$Cu(OH)_2$ $LiNO_3$ NH_4Br K_2SO_4 $PbCl_2$ $BaSO_4$

A. 0
B. 1
C. 2
D. 3
E. 4

T18Q7: Solution

How many of the following compounds are **soluble** in water?

$Cu(OH)_2$ $\boxed{LiNO_3}$ $\boxed{NH_4Br}$ $\boxed{K_2SO_4}$ $PbCl_2$ $BaSO_4$

Soluble Soluble Soluble

A. 0
B. 1
C. 2
D. 3
E. 4

1. Nitrate (NO_3^{-1}) and acetate ($C_2H_3O_2^{-1}$) salts are soluble.
2. Alkali metal (Group 1A) salts and NH_4^+ are soluble.
4. Cl^{-1}, Br^{-1}, and I^{-1} salts are soluble (except when combined with Ag^+, Hg_2^{2+}, Pb^{2+}).
5. Sulfate salts are soluble (except when combined with Ag^+, Hg_2^{2+}, Pb^{2+}, Ca^{2+} , Sr^{2+} and Ba^{2+}).
6. OH^{-1} salts are insoluble (except for those containing Group 1A cations and NH_4^+ which are soluble and those containing Ca^{2+} , Sr^{2+} and Ba^{2+} which are slightly soluble).

T18Q8: Level 1 (L.G. 6)

Choose the reaction that represents a combustion reaction:

A. $C_6H_{12}O_2(l) + 8O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g)$
B. $Mg(s) + Cl_2(l) \rightarrow MgCl_2(aq)$
C. $C_6H_{12}O_2(l) \rightarrow 6C(s) + 6H_2(g) + O_2(g)$
D. $NaOH(aq) + CuCl_2(aq) \rightarrow NaCl_2(aq) + Cu(OH)_2(s)$
E. None of the above are combustion

T18Q8: Solution

Choose the reaction that represents a combustion reaction:

A. $\boxed{C_6H_{12}O_2(l) + 8O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g)}$
B. $Mg(s) + Cl_2(l) \rightarrow MgCl_2(aq)$
C. $C_6H_{12}O_2(l) \rightarrow 6C(s) + 6H_2(g) + O_2(g)$
D. $NaOH(aq) + CuCl_2(aq) \rightarrow NaCl_2(aq) + Cu(OH)_2(s)$
E. None of the above are combustion

A = Combustion (reaction with oxygen)

B = Synthesis (combining things)

C = Decomposition (breaking down)

D = Double displacement (swapping ions)

T18Q9: Level 2 (L.G. 9)

Give the **complete ionic equation** for the reaction that occurs when aqueous solutions of lithium sulfide and copper (II) nitrate are mixed:

A. $Li^{+}(aq) + SO_4^{2-}(aq) + Cu^{+}(aq) + NO_3^{-}(aq)$
$\rightarrow CuS(s) + Li^{+}(aq) + NO_3(aq)$

B. $Li^{+}(aq) + S^{-}(aq) + Cu^{+}(aq) + NO_3^{-}(aq)$
$\rightarrow CuS(s) + LiNO_3(aq)$

C. $2Li^{+}(aq) + S^{2-}(aq) + Cu^{2+}(aq) + 2NO_3^{-}(aq)$
$\rightarrow Cu^{2+}(aq) + S^{2-}(aq) + 2LiNO_3(s)$

D. $2Li^{+}(aq) + S^{2-}(aq) + Cu^{2+}(aq) + 2NO_3^{-}(aq)$
$\rightarrow CuS(s) + 2Li^{+}(aq) + 2NO_3^{-}(aq)$

Topic 18B

Solutions

Peer Instruction
Clicker Session 21

T18Q1: Level 2 (L.G. 9)

Give the **complete ionic equation** for the reaction that occurs when aqueous solutions of lithium sulfide and copper (II) nitrate are mixed:

A. $Li^{+}(aq) + SO_4^{2-}(aq) + Cu^{+}(aq) + NO_3^{-}(aq)$

$\rightarrow CuS(s) + Li^{+}(aq) + NO_3(aq)$

B. $Li^{+}(aq) + S^{-}(aq) + Cu^{+}(aq) + NO_3^{-}(aq)$

$\rightarrow CuS(s) + LiNO_3(aq)$

C. $2Li^{+}(aq) + S^{2-}(aq) + Cu^{2+}(aq) + 2NO_3^{-}(aq)$

$\rightarrow Cu^{2+}(aq) + S^{2-}(aq) + 2LiNO_3(s)$

D. $2Li^{+}(aq) + S^{2-}(aq) + Cu^{2+}(aq) + 2NO_3^{-}(aq)$

$\rightarrow CuS(s) + 2Li^{+}(aq) + 2NO_3^{-}(aq)$

T18Q1: Solution

Give the **complete ionic equation** for the reaction that occurs when aqueous solutions of lithium sulfide and copper (II) nitrate are mixed:

A. $Li^{+}(aq) + SO_4^{2-}(aq) + Cu^{+}(aq) + NO_3^{-}(aq)$
$\rightarrow CuS(s) + Li^{+}(aq) + NO_3(aq)$

B. $Li^{+}(aq) + S^{-}(aq) + Cu^{+}(aq) + NO_3^{-}(aq)$
$\rightarrow CuS(s) + LiNO_3(aq)$

C. $2Li^{+}(aq) + S^{2-}(aq) + Cu^{2+}(aq) + 2NO_3^{-}(aq)$
$\rightarrow Cu^{2+}(aq) + S^{2-}(aq) + 2LiNO_3(s)$

D. $\boxed{2Li^{+}(aq) + S^{2-}(aq) + Cu^{2+}(aq) + 2NO_3^{-}(aq) \rightarrow CuS(s) + 2Li^{+}(aq) + 2NO_3^{-}(aq)}$

Complete Ionic Equation:
contains the solids and ALL the ionic species

T18Q2: Level 2 (L.G. 9)

Give the **net ionic equation** for the reaction that occurs when aqueous solutions of barium nitrate and ammonium phosphate are mixed:

A. $3Ba(NO_3)_2(aq) + 2(NH_4)_3PO_4(aq) \rightarrow Ba_3(PO_4)_2(s) + 6NH_4NO_3(aq)$

B. $3Ba(NO_3)_2(aq) + 2(NH_4)_3PO_4(aq) \rightarrow Ba_3(PO_4)_2(aq) + 6NH_4NO_3(s)$

C. $2NO_3^-(aq) + 6NH_4^+(aq) \rightarrow 6NH_4NO_3(s)$

D. $3Ba^{2+}(aq) + 2PO_4^-(aq) \rightarrow Ba_3(PO_4)_2(s)$

E. $2NO_3^-(aq) + 6NH_4^+(aq) + 2PO_4^-(aq) \rightarrow Ba_3(PO_4)_2(s) + 6NH_4^+(aq) + NO_3^-(aq)$

T18Q2: Solution

Give the **net ionic equation** for the reaction that occurs when aqueous solutions of barium nitrate and ammonium phosphate are mixed:

A. $3Ba(NO_3)_2(aq) + 2(NH_4)_3PO_4(aq) \rightarrow Ba_3(PO_4)_2(s) + 6NH_4NO_3(aq)$

B. $3Ba(NO_3)_2(aq) + 2(NH_4)_3PO_4(aq) \rightarrow Ba_3(PO_4)_2(aq) + 6NH_4NO_3(s)$

C. $2NO_3^-(aq) + 6NH_4^+(aq) \rightarrow 6NH_4NO_3(s)$

D. $\boxed{3Ba^{2+}(aq) + 2PO_4^-(aq) \rightarrow Ba_3(PO_4)_2(s)}$

E. $2NO_3^-(aq) + 6NH_4^+(aq) + 2PO_4^-(aq) \rightarrow Ba_3(PO_4)_2(s) + 6NH_4^+(aq) + NO_3^-(aq)$

Net Ionic Equation:

Only the species that ACTUALLY react to form a solid!

All NH_4^+ and NO_3^- ion salts are soluble so any species with those ions will cancel out

T18Q3: Level 3 (L.G. 10)

Consider the decomposition of calcium carbonate to form calcium oxide and carbon dioxide. If the reaction produced 732 mL of CO_2 at 21°C and 77.1 cm Hg, how many grams of CaO are produced?

A. **0.21 g**
B. **1.73 g**
C. **1.86 g**
D. **3.10 g**
E. **17.2 g**

T18Q3: Solution

Consider the decomposition of calcium carbonate to form calcium oxide and carbon dioxide. If the reaction produced 732 mL of CO_2 at 21°C and 77.1 cm Hg, how many grams of CaO are produced?

A. 0.21 g
B. $\boxed{1.73 \text{ g}}$
C. 1.86 g
D. 3.10 g
E. 17.2 g

1 $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

77.1 cm Hg = 1.01 atm
21°C = 294 K

2 $PV = nRT$

$n = PV/RT$
$= (1.01 \text{ atm})(0.732\text{L})/(0.082 \text{ L-atm/mol-K})(294 \text{ K})$
$= 0.031$ moles

3 1:1 mole ratio
0.031 moles CaO

4 0.031 moles CaO x 56.08 g/mol
= 1.73 grams

T18Q4: Level 3 (L.G. 10)

Consider the reaction between 100 mL of 0.41 M iron(II) nitrate with 63 mL of 0.35M potassium phosphate. How many moles of precipitate are formed from this reaction?

A. **0.011**
B. **0.014**
C. **0.022**
D. **0.041**

T18Q4: Solution

Consider the reaction between 100 mL of 0.41 M iron(II) nitrate with 63 mL of 0.35M potassium phosphate. How many moles of precipitate are formed from this reaction?

1 $3Fe(NO_3)_2(aq) + 2K_3PO_4(aq) \rightarrow 6KNO_3(aq) + Fe_3(PO_4)_2(s)$

A. 0.011
B. 0.014
C. 0.022
D. 0.041

2 $M = \frac{\text{moles of solute}}{\text{volume of solution (L)}}$ moles = M x vol (L)

3 LR calcs

$3Fe(NO_3)_2$	$2K_3PO_4$
0.41 M x 0.100 L = 0.041 mol	0.35 M x 0.063 L = 0.0221 mol
0.041 x (1/3) = 0.014 mol $Fe_3(PO_4)_2$	0.0221 x (1/2) = 0.011 mol $Fe_3(PO_4)_2$

T18Q5: Level 3 (L.G. 10)

What mass, in g, of AgCl is formed from the reaction of 75.0 mL of a 0.078 M $AgC_2H_3O_2$ solution with 55.0 mL of 0.109 M $MgCl_2$ solution?

A. **0.860 g**
B. **1.72 g**
C. **2.56 g**
D. **3.20 g**

T18Q5: Solution

What mass, in g, of AgCl is formed from the reaction of 75.0 mL of a 0.078 M $AgC_2H_3O_2$ solution with 55.0 mL of 0.109 M $MgCl_2$ solution?

1 $2AgC_2H_3O_2(aq) + MgCl_2(aq) \rightarrow 2AgCl(s) + Mg(C_2H_3O_2)_2(aq)$

A. 0.860 g
B. 1.72 g
C. 2.56 g
D. 3.20 g

2 $M = \dfrac{\text{moles of solute}}{\text{volume of solution (L)}}$ moles = M x vol (L)

	$AgC_2H_3O_2$	$MgCl_2$
	0.078 M x 0.075 L = 0.006 mol	0.109 M x 0.055 L = 0.0060 mol
LR calcs 3	0.006 x (2/2) = 0.006 mol AgCl	0.006 x (2/1) = 0.012 mol AgCl
4	0.006 mol x (143.35 g / 1 mol) = 0.86 g	