Answers to Practice Test Questions 7
More Metals and Ionic Solids

1. *Only one answer required for each blank; "/" indicates possible choices*

(a) cobalt(II) bromide
(b) Mg^{2+} and Ca^{2+}
(c) beryllium (Be)
(d) Cu_3N
(e) aluminium oxide (Al_2O_3)
(f) beryllium oxide (BeO) / aluminium oxide (Al_2O_3)
or any other oxide of a group 13 element
(g) iron(III) oxide (Fe_2O_3)
(h) carbon dioxide (CO_2)
(i) barium carbonate ($BaCO_3$)
(j) negative

2.

Chemical Formula	**Name**
Na_2O	sodium oxide
Li_2S	lithium sulfide
$CoCl_3$	cobalt(III) chloride
Mg_3N_2	magnesium nitride
CrI_2	chromium(II) iodide
$TiBr_4$	titanium(IV) bromide

3.

(a) $2Na(s) + I_2(s) \rightarrow 2NaI(s)$ sodium iodide

(b) $6Li(s) + N_2(g) \rightarrow 2Li_3N(s)$ lithium nitride

(c) $4Li(s) + O_2(g) \rightarrow 2Li_2O(s)$ lithium oxide

(d) $2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$ potassium hydroxide *and* hydrogen gas

or $2K(s) + 2H_2O(l) \rightarrow 2K^+(aq) + 2OH^-(aq) + H_2(g)$

potassium cation *and* hydroxide anion *and* hydrogen gas

(e) $2Ca(s) + O_2(g) \rightarrow 2CaO(s)$ calcium oxide

(f) $Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$ magnesium hydroxide *and* hydrogen gas

(g) $2Ga(l) + 3Br_2(l) \rightarrow 2GaBr_3(s)$ gallium bromide

(h) $CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$ calcium oxide *and* carbon dioxide

(i) $MgCO_3(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2O(l) + CO_2(g)$

magnesium chloride *and* water *and* carbon dioxide

or $MgCO_3(s) + 2H^+(aq) \rightarrow Mg^{2+}(aq) + H_2O(l) + CO_2(g)$

magnesium cation *and* water *and* carbon dioxide

4.

(a) $2Al(s) + 3Br_2(l) \rightarrow 2AlBr_3(s)$

(b) $2Al(s) + 2NaOH(aq) + 6H_2O(l) \rightarrow 2Na[Al(OH)_4](aq) + 3H_2(g)$

or $2Al(s) + 2OH^-(aq) + 6H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq) + 3H_2(g)$

(c) $Al_2O_3(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 3H_2O(l)$

(d) $Al_2O_3(s) + 2NaOH(aq) + 3H_2O(l) \rightarrow 2Na[Al(OH)_4](aq)$

or $Al_2O_3(s) + 2OH^-(aq) + 3H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq)$

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

or $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$

(f) $MgCO_3(s) \xrightarrow{\Delta} MgO(s) + CO_2(g)$

5.

(a) $BeO(s) + 2HCl(aq) \rightarrow BeCl_2(aq) + H_2O(l)$

or $BeO(s) + 2H^+(aq) \rightarrow Be^{2+}(aq) + H_2O(l)$

$Be^{2+}(aq)$ can also be written as $[Be(OH_2)_4]^{2+}(aq)$. Four waters are added to the other side of the equation to make it balance. The equation must then be simplified so that only one side has water.

(b) $Na_2CO_3(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + CO_2(g)$

or $Na_2CO_3(s) + 2H^+(aq) \rightarrow 2Na^+(aq) + H_2O(l) + CO_2(g)$

(c) $2K(s) + 2HCl(aq) \rightarrow 2KCl(aq) + H_2(g)$

or $2K(s) + 2H^+(aq) \rightarrow 2K^+(aq) + H_2(g)$

6. The beryllium oxide reaction because beryllium cations are highly toxic.

<u>or</u> The potassium reaction. Potassium reacts violently with water. It will react even more violently with acid. This is most likely an explosive reaction!!! *Most TAs would be more scared of this reaction (depending on the quantity of potassium used).*

7.

(a) Hard water is water containing Ca^{2+} and/or Mg^{2+} cations.

It may also contain other cations with large positive charges. e.g. Fe^{3+}

(b) Water dissolves minerals such as $MgCO_3$ or $CaCO_3$ as it passes through limestone, etc.

This is possible because CO_2 from the air dissolves in water, making the water acidic:

$$H_2O(l) + CO_2(g) \rightleftharpoons H_2CO_3(aq)$$

The acidic water dissolves carbonates, making soluble bicarbonates:

$$CaCO_3(s) + H_2CO_3(aq) \rightleftharpoons Ca(HCO_3)_2(aq)$$

(c) Heating water reduces the solubility of gases such as CO_2. This makes the water less acidic and some of the soluble bicarbonates are converted back to carbonates and precipitate out. This is an example of Le Châtelier's principle as removal of $CO_2(g)$ drives both equilibria shown in part (b) toward the reactant side.

(d) Water can be softened. In other words, remove the Ca^{2+}, Mg^{2+}, etc. cations.

One way to do this is to use an ion exchange column in which anionic beads are initially saturated with Na^+ cations. When hard water passes through the ion exchange column, the Ca^{2+}/Mg^{2+}/etc. cations are more strongly attracted to the anionic beads than the Na^+ cations were. So, the Ca^{2+}/Mg^{2+}/etc. cations adsorb to the beads and Na^+ cations are released into the water.

Since Na_2CO_3 is more soluble in water than $CaCO_3$ or $MgCO_3$, it does not precipitate to the the same extent when the water is boiled and the CO_2 evaporates out of solution.

(e) $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2O(l) + CO_2(g)$

or $CaCO_3(s) + 2H^+(aq) \rightarrow Ca^{2+}(aq) + H_2CO_3(aq)$ <u>and</u> $H_2CO_3(aq) \rightleftharpoons H_2O(l) + CO_2(g)$

The second two equations combine to give the overall equation listed as the first answer.

8. $Ca(OH)_2(s) + Ca(HCO_3)_2(aq) \rightarrow 2CaCO_3(s) + 2H_2O(l)$

or $Ca(OH)_2(s) + Ca^{2+}(aq) + 2HCO_3^-(aq) \rightarrow 2CaCO_3(s) + 2H_2O(l)$

9. $BaCO_3$

$BaCO_3$ and $BaSO_4$ are both insoluble in water; however, $BaCO_3$ reacts with stomach acid, releasing toxic Ba^{2+}(aq) cations:

$BaCO_3(s) + 2H^+(aq) \rightarrow Ba^{2+}(aq) + H_2O(l) + CO_2(g)$

$BaSO_4$ does not react with acid.

10. Pure aluminium reacts quickly with oxygen to form a thin layer of aluminium oxide on its surface. This layer of aluminium oxide does not react further with oxygen. As such, aluminium products do not rust.

This effect can be enhanced by "anodizing" the aluminium which deposits a slightly thicker film of aluminium oxide on the surface of the aluminium.

11. Use HCl.

HNO_3 is an oxidizing acid; HCl isn't.

12.

(a) beryllium oxide = ___BeO___ aluminium oxide = ___Al_2O_3___

(b) A strong base (concentrated hydroxide solution) is added to the mixture of solid metal oxides. The $Al_2O_3(s)$ reacts to give the $[Al(OH)_4]^-(aq)$ ion while the $Fe_2O_3(s)$ does not react. The $Fe_2O_3(s)$ can then be filtered out of solution.

After the Fe_2O_3 has been removed, a weak acid (such as dry ice) is added to react with the $[Al(OH)_4]^-(aq)$ ion, giving aluminium salts (Al_2O_3 and/or $Al(OH)_3$ and/or $AlO(OH)$) which precipitate out of solution and can be isolate via filtration.

(c) This method will not work to separate BeO and Al_2O_3.

BeO is an amphoteric oxide like Al_2O_3. The BeO will also react with the strong base, forming the $[Be(OH)_4]^{2-}(aq)$ ion. Since both species have dissolved, this method does not allow them to be separated.

13. Al_2O_3 is an amphoteric oxide. CuO is a basic oxide (like most metal oxides except BeO and Al_2O_3).

As such, Al_2O_3 will react with base and can therefore be dissolved in aqueous base:

$$Al_2O_3(s) + 2OH^-(aq) + 3H_2O(l) \rightarrow 2[Al(OH)_4]^-(aq)$$

CuO will not react with aqueous base, so CuO(s) can be filtered out.

To get the $Al_2O_3(s)$ back, add acid to neutralize the anion then heat to dehydrate and evaporate off the resulting water:

$$[Al(OH)_4]^-(aq) + H^+(aq) \rightarrow Al(OH)_3(s) + H_2O(l)$$

then

$$2Al(OH)_3(s) \rightarrow Al_2O_3(s) + 3H_2O(g)$$

This is exactly the same method used to remove contaminants such as Fe_2O_3 from bauxite (see answer to question 12(b).

14.

(a)

Method A: Dissolve each salt in water then perform a flame test on the resulting solutions. The $BaCl_2$ solution will give a green flame. The KCl solution will give a purple flame.

Method B: Dissolve each salt in water. Add sulfuric acid (H_2SO_4) to each solution. The one that forms a precipitate ($BaSO_4$) contained $BaCl_2$.

There are other solutions that could be used instead of $H_2SO_4(aq)$ – anything that would give an insoluble barium salt through a double replacement reaction.

(b)

Method A: Gently heat both vials. The gallium will melt at ~30 °C. Aluminium does not melt until much hotter (660 °C).

Method B: Weigh a sample of each metal then determine its volume by displacement of a liquid. Use the mass and volume of each piece of metal to determine its density. The density of gallium is greater than the density of aluminium. (Density generally increases from top to bottom within a group.)

This method requires a relatively large sample of each metal so may be less practical than Method A.

(c)

Method A: Calcium reacts violently with water; zinc does not react at all with water. Set up a beaker of water behind a blast shield. Drop a small piece of one metal into the water. If there is no reaction, it was zinc. If there is a reaction producing a gas (H_2), it was calcium. Repeat the procedure with the other metal to confirm that only one reacts.

Method B: Weigh a sample of each metal then determine its volume by displacement of a an inert liquid such as oil. Use the mass and volume of each piece of metal to determine its density. The density of zinc is greater than the density of calcium. *This method requires a relatively large sample of each metal so may be less practical than Method A. It has the advantage of being safer though.*

15.

(a) $CaCO_3(s) \xrightarrow{\Delta} CaO(s) + CO_2(g)$

(b)	$CaCO_3(s)$	→	$CaO(s)$	+	$CO_2(g)$
M	100.087 g/mol		56.077 g/mol		44.0098 g/mol
$m_{initial}$	17.67 g				
P					0.987 bar
T					297.65 K
$n_{initial}$	0.1765 mol		0 mol		0 mol
n_{change}	-0.1765 mol		+0.1765 mol		+0.1765 mol
n_{final}	0 mol		0.1765 mol		0.1765 mol
V_{final}					0.00443 m^3 = 4.43 L

Step 1: Write a balanced chemical equation for the reaction

see above

Step 2: Organize all known information

see above; values in grey are not necessary for this calculation

Step 3: Calculate moles of $CaCO_3$ ($n_{initial}$)

$$n_{CaCO_3-initial} = 17.67g \times \frac{1mol}{100.087g} = 0.1765mol$$

Step 4: Use mole ratio to calculate moles of CO_2 produced (n_{final})

$$n_{CO_2-final} = 0.1765\ mol\ CaCO_3 \times \frac{1\ mol\ CO_2}{1\ mol\ CaCO_3} = 0.1765\ mol\ CO_2$$

Step 5: Calculate volume of CO_2 produced in (V_{final})

$$PV = nRT$$

$$V_{CO_2-final} = \frac{nRT}{P} = \frac{(0.1765mol)\left(8.3145\frac{Pa\cdot m^3}{mol\cdot K}\right)(297.65K)}{(0.987bar)} \times \frac{1bar}{10^5Pa} = 0.00443m^3$$

$$V_{CO_2-final} = 0.00443m^3 \times \frac{1000L}{1m^3} = 4.43L$$

Step 6: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

16.

(a) $H_2CrO_4(aq) + BaCl_2(aq) \rightarrow BaCrO_4(s) + 2HCl(aq)$

(b)	$H_2CrO_4(aq)$	+	$BaCl_2(aq)$	→	$BaCrO_4(s)$	+	2 $HCl(aq)$
M	118.0095 g/mol		208.2324 g/mol		253.3207 g/mol		36.4606 g/mol
$m_{initial}$			3.75 g				
$c_{initial}$	1.25 mol/L						
V	75.00 mL						
$n_{initial}$	0.0938 mol		0.0180 mol		0 mol		0 mol
n_{change}	-0.0180 mol		-0.0180 mol		+0.0180 mol		+0.0360 mol
n_{final}	0.0757 mol		0 mol		0.0180 mol		0.0360 mol
m_{final}					4.56 g		

Step 1: Write a balanced chemical equation for the reaction

see part (a)

Step 2: Organize all known information

see above; values in grey are not necessary for this calculation

Step 3: Calculate moles of H_2CrO_4 and $BaCl_2$ ($n_{initial}$)

$$n_{BaCl_2-initial} = 3.75g \times \frac{1mol}{208.2324g} = 0.0180mol$$

$$n_{H_2CrO_4-initial} = 75.00mL \times \frac{1L}{1000mL} \times \frac{1.25mol}{1L} = 0.0938mol$$

Step 4: Identify the limiting reagent

0.0180 mol H_2CrO_4 are required to react with 0.0180 mol $BaCl_2$. Since there is more H_2CrO_4 than this, the $BaCl_2$ will run out before the H_2CrO_4. $BaCl_2$ is therefore the limiting reagent.

Step 5: Use mole ratio to calculate moles of $BaCrO_4$ produced (n_{final})

$$n_{BaCrO_4-final} = 0.0180\ mol\ BaCl_2 \times \frac{1\ mol\ BaCrO_4}{1\ mol\ BaCl_2} = 0.0180\ mol\ BaCrO_4$$

Step 6: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

(c) $BaCrO_4$ forms a stronger lattice because the charge of the chromate ion (CrO_4^{2-}) is more negative than the charge of the chloride ion (Cl^-). This means that the ion-ion attractive forces are stronger in $BaCrO_4$ than in $BaCl_2$.

17.

(a) $2\,Al_2O_3(l) + 3C(s) \rightarrow 4Al(l) + 3CO_2(g)$

(b)	$2\ Al_2O_3(l)$	+	$3\ C(s)$	→	$4\ Al(s)$	+	$3\ CO_2(g)$
M	101.9612 g/mol		12.011 g/mol		26.9815 g/mol		44.0098 g/mol
m_{final}					1000 kg		
$n_{initial}$					0 mol		0 mol
n_{change}					$+3.71\times10^4$ mol		$+2.78\times10^4$ mol
n_{final}					3.71×10^4 mol		2.78×10^4 mol

Step 1: Write a balanced chemical equation for the reaction

see part (a)

Step 2: Organize all known information

see above; values in grey are not necessary for this calculation

Step 3: Calculate moles of Al produced (n_{final})

$$n_{Al-final} = 1000kg \times \frac{1000g}{1kg} \times \frac{1mol}{26.9815g} = 3.71 \times 10^4 mol$$

Step 4: Use mole ratio to calculate moles of CO_2 produced (n_{final})

$$n_{CO_2-final} = 3.71 \times 10^4 mol\ Al \times \frac{3\ mol\ CO_2}{4\ mol\ Al} = 2.78 \times 10^4\ mol\ CO_2$$

Step 5: Calculate mass of CO_2 produced (m_{final})

$$m_{CO_2-final} = 2.78 \times 10^4\ mol\ CO_2 \times \frac{44.0098g}{1\ mol} = 1.22 \times 10^6\ g\ CO_2 = 1.22Mg\ CO_2$$

Step 6: Check your work

Does your answer seem reasonable? Are sig. fig. correct?

The masses of the two products of this reaction are of the same order of magnitude (which is reasonable given that they have similar molar masses and a mole ratio of 4 : 3).