Preliminary Chemistry

Metals

Week 2

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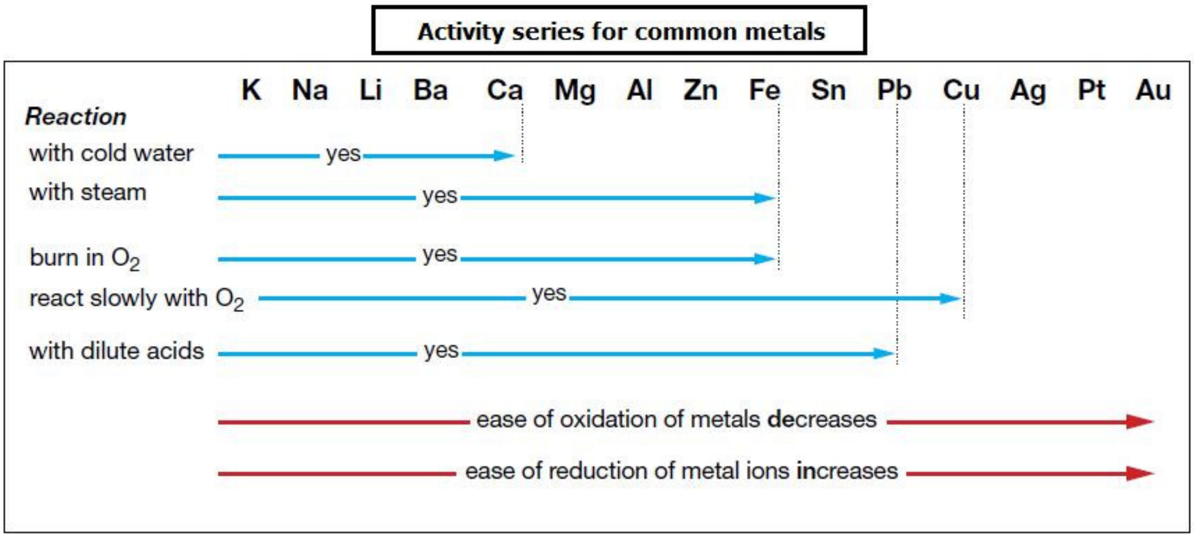
Week 2 – Theory

- **<u>Describe and justify the criteria used to place metals into an order of activity based on their ease of reaction with oxygen, water and dilute acids</u>**

When we compare the reactivities of metals with each other, we need to come up with certain objective criteria which we can use to differentiate between metals in terms of reactivities. Since oxygen, water and dilute acids are very common reagents, we use the reactions between metals and these substances to compare their relative reactivities.

Below is a chart of various common metals and their relative reactivities in terms of their ability to react with water, oxygen and dilute acids. This is called the '**Activities Series**':



Notice that as metals become less reactive, they are less able to react with the common reagents such as oxygen gas, steam, water and even acids. The reason for this is more and more energy is needed to oxidise increasingly less reactive metals such as silver, platinum and gold. Hence, as their ease of oxidation decreases, their ease of reduction should correspondingly increase.

The less reactive a metal is, the less things it will react with. For example, Cu is very unreactive, and will only react slowly with O_2. This indicates that oxidation of Cu is difficult, and Cu is more readily reduced than more reactive metals, such as Zn. Recall from electrochemistry in module 1 that Zn can displace Cu in solution. This is because Zn is more easily oxidised than Cu. The most unreactive metals such as Pt and Au can only be chemically attacked by special mixtures of concentrated acids.

- **<u>Identify the reaction of metals with acids as requiring the transfer of electrons</u>**
- **<u>Construct half-equations to represent the electron transfer reactions occurring when metals react with dilute hydrochloric and dilute sulfuric acids</u>**

When metals react with acids, what is really happening is the metal displaces the hydrogen ion from solution, much like Zn displaces Cu from solution. As this is essentially a displacement reaction, there is a **transfer of electrons**.

For example, when Mg reacts with dilute HCl, this happens:

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

The half equations for this reaction are:

$$Mg_{(s)} \rightarrow Mg^{2+}_{(aq)} + 2e^-$$

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)}$$

Hence a **transfer of electrons** has taken place.

More examples

Example 1: Zinc is placed into a dilute solution of sulfuric acid. The balanced equation is:

$$Zn_{(s)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(aq)} + H_{2(g)}$$

The half equations are:

$$Zn_{(s)} \rightarrow Zn^{2+}_{(aq)} + 2e^- \text{ (oxidation – loss of electrons)}$$

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)} \text{ (Hydrogen ions are reduced – gains electrons)}$$

Example 2: Ca is placed into dilute HCl. The balanced equation is:

Ca(s) + 2HCl(aq) → CaCl2(aq) + H2(g)

The half equations are:

$$Ca_{(s)} \rightarrow Ca^{2+}_{(aq)} + 2e^- \text{ (oxidation – loss of electrons)}$$

$$2H^+_{(aq)} + 2e^- \rightarrow H_{2(g)} \text{ (Hydrogen ions are reduced – gains electrons)}$$

Example 3: Sodium is placed into dilute HNO3 (nitric acid) where it reacted violently and burst into flames. The balanced equation is:

$$2Na_{(s)} + 2HNO_{3(aq)} \rightarrow 2NaNO_{3(aq)} + H_{2(g)}$$

The half equations are:

$$Na_{(s)} \rightarrow Na^{+}_{(aq)} + e^{-} \text{ (oxidation – loss of electrons)}$$

$$2H^{+}_{(aq)} + 2e^{-} \rightarrow H_{2(g)} \text{ (Hydrogen ions are reduced – gains electrons)}$$

Example 4: Iron is placed into dilute H2SO4 and forms iron(II) sulfate. The balanced equation is:

$$Fe_{(s)} + H_2SO_{4(aq)} \rightarrow FeSO_{4(aq)} + H_{2(g)}$$

The half equations are:

$$Fe_{(s)} \rightarrow Fe^{2+}_{(aq)} + 2e^{-} \text{ (oxidation – loss of electrons)}$$

$$2H^{+}_{(aq)} + 2e^{-} \rightarrow H_{2(g)} \text{ (Hydrogen ions are reduced – gains electrons)}$$

As you can see, there is a pattern. The metal is always oxidised and transfers its electrons onto the hydrogen ions, which are reduced and covalently bond to form hydrogen gas. This explains why you will observe bubbles whenever you drop pieces of (reactive) metals into dilute acids, as they are bubbles of hydrogen gas.

- **<u>Outline examples of the selection of metals for different purposes based on their reactivity, with a particular emphasis on current developments in the use of metals</u>**

The unique reactive properties of different metals determine what they will be used for. Below are examples of some metals chosen for special uses because of their unique reactive properties.

Metal	Properties related to reactivity	Uses related to reactive properties
Mg, Al	High reactivity with oxygen, burns at a very high temperature, burns with a very bright light (called 'incendiary' properties) Aluminium metal is corrosion resistant	Fireworks, emergency fire starters (Mg burns so hotly, it will burn even in the rain), military aircraft countermeasures (to mislead heat-seeking missiles) Al is used to make beverage cans due to its corrosion resistance. It forms an impenetrable oxide layer, preventing further corrosion by air or acids (such as in soft drinks).
Ti	Highest tensile strength to weight ratio out of all metals, lightweight, high corrosion resistance	Surgical implants, surgical instruments (as they won't react with bodily fluids such as blood)
Zn	More readily oxidised than iron and steel, cheap and abundant	Used to coat iron / steel structures (called **galvanisation**) in order to prevent them from rusting. Because Zn is more readily oxidised, it will displace iron when the structure comes into contact with water (e.g. when it rains), preventing the iron structure from rusting (until the Zn runs out). Because it is cheap and abundant, Zn can be used in this way. Also used as sacrificial anodes in ship hulls and ship propellers working under the same principle.
Sn	Not as readily oxidised as iron and steel, cheap and abundant	Used to coat iron and steel cans. If no iron is exposed, the less reactive tin protects the iron.
Cr	High corrosion resistance, difficult to oxidise	Used to make stainless steel. Chromium is alloyed with normal steel, with at least 10% by weight Cr content. The Cr in stainless steel will form a protective oxide coating over the stainless steel, preventing further corrosion.
Cu	High corrosion resistance, difficult to oxidise, very stable metal	Water pipes, electrical wires, electrical contacts, outdoor uses. Because copper is very stable and doesn't react with most things commonly encountered, they are suitable for use in making pipes.

- **<u>Outline the relationship between the relative activities of metals and their positions on the Periodic Table</u>**

Recall discussion from the previous module about general trends on the periodic table related to the location of elements. When applied to metals, the same trends exist.

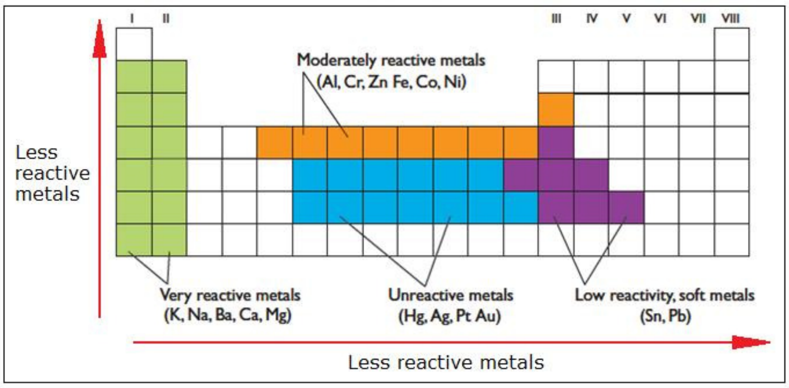
Reactivity increases (electronegativity decreases):

- As you move from right to left
- As you move from bottom to top

Reactivity decreases (electronegativity increases):

- As you move from left to right
- As you move from top to bottom

Reactivity of metals and the periodic table



The general rule is: the more electropositive (less electronegative) metals are, the more reactive they are. Therefore, recall what happens to electronegativity when you move around the periodic table.

As you move to the bottom left, electronegativity is at a minimum, and metals are most reactive. Fr is therefore the most reactive metal.

As you move to the top-right, metals become less reactive.

Remember, for metals, since they like to be oxidised, the LESS electronegative they are, the more reactive they are. As you move left, metals have **fewer and fewer electrons to give away** before they have an empty outer shell (stable). As you move down the table, the **further the outer electron shell becomes** from the nuclei, meaning the electrostatic attraction becomes weaker, allowing for easier oxidation.

Examples

- Na and K are highly reactive metals because they are on the left-most column of the periodic table
- Mg and Ca are also highly reactive, but not as reactive as Na and K, being Group II elements
- Ti and Cr are considered corrosion resistant only because they form a protective oxide layer when exposed to air / water. They are actually quite reactive
- Pt and Au among the most unreactive metals known, and their location are to the right of the table

Note that with transition metals, there is no general pattern, as reactivity behaviour of individual transition metals are affected by more factors. However the trends definitely hold true for non-transition metals.

- **Identify the importance of first ionisation energy in determining the relative reactivity of metals**

Definition

The **ionisation energy** (or ionisation potential, as it is sometimes called) of an atom or molecule is defined as *the energy required to remove one mole of electrons from one mole of gaseous atoms or ions.* (The gaseous requirement is important as it allows for direct comparison, since different states affect ionisation energies)

The **nth ionisation energy** is the energy required to remove the nth electron from the species, after the n-1 electrons have already been removed.

Therefore the ***first*** **ionisation energy of a metal** is the energy needed to remove the *first* electron from a metal atom (assuming it is in a gaseous state). Ionisation energy is measured in kJ/mol.

Relationship to reactivity

The lower the first ionisation energy, the easier it is for the metal to oxidise and give up its first electron. For Group I metals such as Li, Na, K, they only need to give 1 electron before they achieve a stable empty outer shell. **The more easily a metal can give away its first electron, the more reactive it is.** Because all metal reactions involve a transfer of electrons (see above discussion), first ionisation energy is a useful measure and predictor of reactivity of metals.

For example, K's first ionisation energy is among the lowest out of all metals, so it readily gives its first electron away to just about anything it comes into contact with. For example, it gives its electrons away to oxygen in the air, forming its peroxide salt:

$$2K_{(s)} + O_{2(g)} \rightarrow K_2O_{2(s)}$$

As with the discussion about trends on the periodic table, you can actually interpret the trends to indicate that the first ionisation energy decreases as you move down and to the left of the table.

Further ionisation energies

For ionisation energies beyond the first, generally the $n+1^{st}$ ionisation energy is larger than the nth ionisation energy, as it involves removing an electron from an orbital closer to the nucleus. Therefore greater electrostatic attraction between the electron and the positive nucleus must be overcome.

> **For example:** $Mg \rightarrow Mg^+ + e^-$ has a lower ionisation energy than $Mg^+ \rightarrow Mg^{2+} + e^-$. After Mg gives away 2 electrons, it is stable. If we then force it to give away a third electron, it will have an immensely greater ionisation energy compared to the first two. Generally speaking, $Mg^{2+} \rightarrow Mg^{3+} + e^-$ does not happen normally.

- **<u>Perform a first-hand investigation incorporating information from secondary sources to determine the metal activity series</u>**

This dot-point requires students to be able to recall a practical they can use to demonstrate and compare the reactivities of various metals and construct their own activity series. Some common metals you can test available at school labs are:

- Magnesium
- Copper
- Zinc
- Iron
- Lead

Some more dangerous metals that should be tested by the teacher (with everyone wearing safety goggles) are:

- Sodium
- Potassium (highly dangerous)

Method

There are many ways you can test and compare reactivities of metals. The easiest way is to observe the extent of bubbling which occurs. Another is to measure the pH change of a dilute acid solution before and after the metal is allowed to fully react with the solution. The more comprehensive way is to use various salt solutions of the metals tested, and testing whether one metal would displace another by observing whether the metal in solution will deposit onto the solid metal.

Results

These are suggested results. You may experience something slightly different.

Metal	Bubbling	Phenolphthalein colour	Displacements
Mg	Vigorous bubbling	Turned solution pink	Displaced everything tested
Zn	Moderate bubbling	No visible reaction	Displaced Fe, Pb, Cu
Fe	Slight bubbling, barely visible	No visible reaction	Displaced Pb, Cu, after a long wait
Pb	No visible reaction	No visible reaction	Displaced Cu, after a long wait
Cu	No visible reaction	No visible reaction	Displaced nothing

The reason why phenolphthalein was used was to test whether the solution was turned basic after adding the metal. Mg was able to turn the solution basic, as indicated by the indicator turning pink, as a result of Mg reacting slightly with water under acidic conditions to produce hydroxide ions:

$$Mg_{(s)} + 2H_2O_{(l)} \rightarrow Mg(OH)_{2(aq)} + H_{2(g)}$$

From the above selection of metals, you should conclude the following order of activity:

Mg > Zn > Fe > Pb > Cu

And if you tested sodium, it would be more reactive than Mg.

Safety precautions

Sometimes in HSC exams, questions may ask you to identify the risks associated with any experiment required in the syllabus, or methods of dealing with these risks. As a student, each time you go through an experiment, you should be aware of any risks and any safety measures in the experiment.

When dealing with highly reactive and caustic metals like K and Na, extreme caution should be used. Na and K readily reacts with water to form instensely caustic solutions of NaOH and KOH respectively, which can cause instant and painful chemical burns if splashed onto skin. Therefore for the person conducting the experiment involving Na or K, he/she should wear gloves and safety goggles. The latter should also be worn by everyone in the room.

Lead is toxic and contact should be avoided. Dilute acids should be handled carefully, as they can cause rashes if skin contact occurs. Lastly, phenolphthalein should not be handled with bare hands, and only a few drops should be added, as it is suspected of being a carcinogenic (cancer causing) substance.

Week 2 – Homework

- **Describe and justify the criteria used to place metals into an order of activity based on their ease of reaction with oxygen, water and dilute acids**

1. Place the following metals in order of their reactivity from least to most reactive. **[2 marks]**

Ag	Li	Zn	Pb	K	Mg	Cu

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2. On the activity series, aluminium is actually more reactive than iron. Explain why iron chains eventually rust away and snap, but aluminium cans carrying acidic soft-drinks will never rust away. (Hint: mention an oxide layer) **[3 marks]**

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3. Metals are ordered on the activity series based on their reactivity with water, oxygen and dilute acids. Justify the criteria used to place metals into an order of activity such as the activity series. In your answer, explain how reactions with water, oxygen and acids are an important indicator of general reactivity. **[4 marks]**

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4. Explain the relationship between: ease of oxidation, ease of reduction, reactivity. **[2 marks]**

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5. Explain why gold is considered unreactive when it is so easily reduced. **[2 marks]**

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6. Group VII elements are extremely reactive and are easily reduced. Explain how this makes sense with the fact that gold is the most easily reduced metal, but is also the most unreactive. **[3 marks]**

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- **Identify the reaction of metals with acids as requiring the transfer of electrons**
- **Construct half-equations to represent the electron transfer reactions occurring when metals react with dilute hydrochloric and dilute sulfuric acids**

1. Zinc reacts with sulfuric acid to produce hydrogen gas and a salt. Draw a Lewis electron-dot diagram to illustrate the transfer of electrons in this reaction. **[2 marks]**

2. Write half-equations for the following reactions: **[1 mark each]**
   a. Zinc + hydrochloric acid

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   b. Lead + sulfuric acid

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   c. Magnesium + nitric acid

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3. From your answers in question 2, what are the common features shared by all reactions between metals and acids? **[2 marks]**

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4. Write full balanced equations for the following reactions: **[1 mark each]**
    a. Calcium + hydrochloric acid

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    b. Iron + sulfuric acid

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    c. Lead + hydrochloric acid

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    d. Copper + sulfuric acid

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    e. Barium + carbonic acid

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    f. Aluminium + sulfurous acid

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    g. Zinc + nitrous acid

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- **<u>Outline examples of the selection of metals for different purposes based on their reactivity, with a particular emphasis on current developments in the use of metals</u>**

1. Describe the uses of zinc metal in modern society. Relate these uses to its properties. (Hint: whenever you're asked about zinc, think of galvanisation) **[3 marks]**

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2. Chromium is relatively easily corroded by exposure to oxygen and acids, and forms a protective oxide layer, preventing further corrosion. Account for the use of chromium to plate steel, creating stainless steel. **[3 marks]**

3. Aluminium is chosen to hold Coca-cola as a can. Explain why aluminium is suitable for this task, despite its reactivity with dilute acids (such as carbonic acid in soft-drinks). (Hint: whenever asked about aluminium, think of a protective oxide layer). **[3 marks]**

4. Electrical contacts (such as computer plugs) are plated with gold. Account for this usage of gold with respect to gold's relative reactivity. **[3 marks]**

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5. Surgical implements such as scalpels, as well as implants are often made of titanium alloys. Account for this usage with reference to the relative reactivity of titanium. **[3 marks]**

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6. Light bulbs are often evacuated (all oxygen sucked out) and filled with an inert gas such as Argon. Explain why this is necessary. (Hint: the filament is a thin tungsten wire that heats up to 4000°C) **[3 marks]**

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- **<u>Outline the relationship between the relative activities of metals and their positions on the Periodic Table</u>**

1. Identify three group I metals. **[1 mark]**

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2. Identify three group II metals. **[1 mark]**

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3. There are certain trends in terms of metal reactivity and their position on the periodic table.
   a. Identify these trends **[2 marks]**

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   b. Explain these trends in terms of relative electronegativity. **[3 marks]**

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4. According to your study of trends, which metal should be the most reactive? Comment on that metal's electronegativity. **[2 marks]**

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5. Explain why reactivity increases and electronegative decreases when you move left in the periodic table. **[2 marks]**

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6. Explain why platinum and gold are so unreactive. **[2 marks]**

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- **Identify the importance of first ionisation energy in determining the relative reactivity of metals**

1. Identify the relationship between the first ionisation energy and the relative reactivity of metals. **[1 mark]**

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2. Define ionisation energy. In your answer, define first ionisation energy. **[2 marks]**

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3. Explain why removing a second electron from a sodium atom requires a large amount of energy. **[3 marks]**

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4. Outline qualitatively the first 3 ionisation energies for a group II metal. **[2 marks]**

5. Explain the relationship between ionisation energy and reactivity of a metal. Give at least two examples in your answer. **[4 marks]**

6. With reference to the trends you have studied about the periodic table, predict the trend for ionisation energy in terms of the location of metals on the periodic table. **[3 marks]**

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- **Perform a first-hand investigation incorporating information from secondary sources to determine the metal activity series**

1. Briefly outline how a student may be able to test the relative reactivities of a selection of metals, given some dilute acid, water, and salt solutions. **[3 marks]**

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2. Explain why merely observing the bubbling rate is not adequate in precisely determining an activity series. **[1 mark]**

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3. Explain the role played by salt solutions in a practical demonstrating an activity series. **[2 marks]**

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4. Outline two potential sources of error in your procedure. **[2 marks]**

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End of homework