Metal Reactivity:

1. Reactivity of Metals
    a. Reaction with water, steam or dilute hydrochloric acid

<table>
<tr><th>Metal</th><th>Reaction with Cold Water</th><th>Reaction with Steam</th><th>Reaction with dilute strong acid</th></tr>
<tr><td>K</td><td rowspan="4">Displaces H2 from cold water with decreasing reactivity (K: violent, Mg: very slowly) – the corresponding hydroxide is formed</td><td rowspan="5">Displaces H2 from steam with decreasing vigour (K: very violently, Sn: very slowly) – corresponding oxide is formed</td><td rowspan="5">Displaces H2 from dilute strong acids with decreasing vigour (K: explosively, Mg: very vigorously, Fe: steadily, Pb: very slowly)</td></tr>
<tr><td>Na</td></tr>
<tr><td>Ca</td></tr>
<tr><td>Mg</td></tr>
<tr><td>Al</td><td rowspan="7">Does not displace H2 from cold water</td></tr>
<tr><td>Zn</td><td rowspan="6">Does not displace H2 from steam</td><td rowspan="4">Does not displace H2 from dilute strong acid</td></tr>
<tr><td>Fe</td></tr>
<tr><td>Sn</td></tr>
<tr><td>Pb</td></tr>
<tr><td>Cu</td><td rowspan="3"></td></tr>
<tr><td>Ag</td></tr>
<tr><td>Au</td></tr>
</table>

- Note: dilute strong acid does not mean concentrated acid (strong acid: complete dissociation)
- Note: dilute strong acid refers to dilute HCl or H2SO4, HNO3 may produce NO or NO2 instead of H2

<table>
<tr><th>Metal</th><th>Reaction with O2 on heating</th><th>Reaction with Cl2 on heating</th></tr>
<tr><td>K</td><td rowspan="2">Form oxides (Na2O) in limited supplies of O2, but peroxides (Na2O2) with excess O2</td><td rowspan="11">All metals react with Cl2 on heating to form the corresponding chloride with decreasing vigour</td></tr>
<tr><td>Na</td></tr>
<tr><td>Ca</td><td rowspan="6">Burning with decreasing vigour to form oxides</td></tr>
<tr><td>Mg</td></tr>
<tr><td>Al</td></tr>
<tr><td>Zn</td></tr>
<tr><td>Fe</td></tr>
<tr><td>Sn</td></tr>
<tr><td>Pb</td><td rowspan="2">Do not burn, but only form a surface layer of oxide</td></tr>
<tr><td>Cu</td></tr>
<tr><td>Ag</td><td rowspan="2">Do not burn or oxidize on surface</td></tr>
<tr><td>Au</td></tr>
</table>

- The metals that show very little reaction with air appear bright and shiny (silver and gold) while those that react quickly with air appear dull (sodium and magnesium)
    - The difference in appearance of the metals is due to their reactivity with oxygen
    - Potassium and sodium reacts with oxygen to form a layer of oxide on the surface of metals
    - Oxide layers are dull and cover the shiny metal beneath

2. Describe the reactivity series as related to the tendency of a metal to form its positive ion through electron loss, illustrated by reaction with: aqueous ions of other metals and oxides of other metals

- **A more reactive metal will displace a less reactive metal from its compound**, since the more reactive metal loses electrons more easily and thus forms more stable compounds
- **A more reactive metal is a stronger reducing agent**
    - For Fe metal and Ag+ ion, iron is the reducing agent, since the oxidation state of Ag decreased from +1 in Ag+ to 0 in Ag, thus iron itself becomes oxidized
- **Metals with a larger atomic radius are more reactive**
    - The valence electrons are located further away from the nucleus when the atoms become larger, and the metal will then lose its electrons more easily, thus the metal is more likely to be reactive (potassium more reactive than calcium which is in Group II)
- Note:

- K to Al are considered very reactive metals (Carbon is below Al)
- Zn to Pb are moderately reactive metals (H is below Pb)
- Cu to Au are less reactive metals
- No metal can be considered unreactive

3. Describe the action of heat on the carbonates and nitrates and relate their thermal stability to the reactivity of the metal

- Metal compounds such as metal carbonates and metal nitrates (and sometimes metal oxides) will **undergo thermal decomposition to form products** which are more stable
- The products can be observed to derive the thermal stability of the metal compound and reactivity of the metal (element/atom)
- The **speed** at which the products are formed (speed of decomposition) is also used to deduce the relative thermal stability of the metal compound

Trends:

- The more reactive a metal, the more thermally stable the compound of the metal
- The larger the atomic radius of the metal, the greater the reactivity of the metal, thus the greater the thermal stability of the metal compound

<table>
<tr><th>Metal</th><th>Metal Oxides</th><th>Metal Hydroxides</th><th>Metal Carbonates</th><th>Metal Nitrates</th></tr>
<tr><td>K</td><td rowspan="10">Stable to heating</td><td>Stable to heating</td><td>Stable to heating</td><td>Metal nitrite (NO2) and oxygen</td></tr>
<tr><td>Na</td><td rowspan="9">Metal oxide and steam</td><td rowspan="9">Metal oxide and carbon dioxide</td><td rowspan="9">Metal oxide, nitrogen dioxide and oxygen</td></tr>
<tr><td>Ca</td></tr>
<tr><td>Mg</td></tr>
<tr><td>Al</td></tr>
<tr><td>Zn</td></tr>
<tr><td>Fe</td></tr>
<tr><td>Sn</td></tr>
<tr><td>Pb</td></tr>
<tr><td>Cu</td></tr>
<tr><td>Ag</td><td rowspan="2">Metal and oxygen</td><td rowspan="2">Do not form hydroxides</td><td rowspan="2">Metal, carbon dioxide and oxygen</td><td rowspan="2">Metal, nitrogen dioxide and oxygen</td></tr>
<tr><td>Au</td></tr>
</table>

4. Describe the ease of obtaining metals from their ores by relating the elements to their positions in the reactivity series

- The more reactive the metal, the more difficult it is to extract the metal from the metal ore
  - For very reactive metals (K, Na, Ca, Mg, Al), electricity must be used to extract metal from ion (very stable ore)
  - For less reactive metals (below C), the metal ions in the ore must be reduced (gain electron) to extract the metal (by adding carbon to the ore, which is an inexpensive process)
- Most metals found in the ground are compounds known as minerals
  - Impure minerals are known as ores (more common)
  - Mineral must be separated from the useless compounds in the ores by physical methods
  - Pure metals extracted from minerals by electrolysis or by chemical reduction
- In general, the less reactive the metal, the earlier it was discovered by humans (gold, silver)

5. Describe the metal ores as a finite resource and hence the need to recycle metals

- Silver will run out in an estimated 20 years without recycling
- Metal is a finite resource (can run out in the future)
- Conservation: use other materials in place of metals
- Conservation: recycling of metals and their alloys

6. Discuss the social, economic and environmental advantages and disadvantages of recycling metals

Benefits	Disadvantages
Conservation of metals	Processes during recycling create pollution (smelting)
Saves the need of extracting new metals, saving the environment as most mining and extraction processes damage the environment (pollution)	Costly: collecting and transporting scrap metals, sorting, separating and cleaning the scrap metals etc.
Prevent the landfills from filling up too quickly	Some alloys not recycled due to difficulty in separating metals in alloys

7. Account for the apparent unreactivity of aluminium in terms of the presence of a non-porous oxide layer that adheres to the metal

- Oxide layer protects the metal from further reaction with air and is impervious
    - Once the oxide layer forms, reaction cannot occur with the internal layer of aluminium
    - Reason: prevents oxygen and water from penetrating into the metal to corrode it
- Sodium and iron react with air to form oxide layers that destroy the metal (since the oxide layer is porous and tends to fall off to expose a fresh metal surface to the air)
    - Porous oxide layer allows oxygen and moisture to penetrate and attack metal underneath
- Thus, aluminium does not need to be kept in oil or be painted
- To protect aluminium even more, the oxide layer can be made thicker, by anodizing (electrolysis)
    - Dyes can be introduced which are absorbed onto the oxide layer (colouring and protecting)

8. Describe the production of electrical energy from simple cells, through the use of two metal electrodes of different reactivities in an electrolyte (oxidation and reduction half equations)

The Electric Cell:

- **Made up of 2 electrodes of 2 metals of different reactivities immersed in an electrolyte**
    - Electrolyte must contain free, mobile ions in aqueous or molten form
    - Note: electrolytes in the solid form will prevent electrical cell from working
    - Note: for the cell to act as a battery, the two electrodes *cannot be in contact* with one another, since electrons would flow directly from one metal to the other
    - A wire (or at least electrical conductor) must connect the two electrodes
- **Electrons flow form the more reactive to less reactive metal through the wire**
    - Reason: potential difference set up between the two electrodes (electricity is produced)
- More reactive metal loses electrons (more easily) and oxidation occurs (X -> X+ and e-)
    - Electrons move through the wire to the other electrode
    - The less reactive metal receives electrons and passes them to the electrolyte
    - The cation in the electrolyte accepts the electrons and reduction occurs (Y+ and e- -> Y)
    - Note: more reactive metal (at the anode) becomes smaller as reaction progresses (and the metal ion enters the electrolyte)
    - Note: the cation in the electrolyte upon being reduced, forms a gas/metal/substance
- **The more reactive metal is the anode and negative electrode**
    - Oxidation always occurs at the anode (and electron flow is always from anode to cathode)
- **The less reactive metal is the cathode and positive electrode**
    - Reduction always occurs at the cathode
- The further apart the two metal electrodes are in the reactivity series, the greater the voltage of the electric cell
- Electric cell converts chemical energy to electrical energy

Hydrogen Fuel Cell:

- Hydrogen is a colourless, odourless and neutral gas that is highly flammable
- Identified when a pop sound is heard as a burning splint is introduced into the gas
- Acts as an important fuel
- *Advantages of Hydrogen:*
    - Burns cleanly in air, producing only steam (a non-pollutant) while other hydrocarbon fuels produce carbon monoxide and carbon dioxide
    - Produces at least twice as much heat energy per gram when burnt than any other fuel
- *Disadvantages of Hydrogen:*
    - Low boiling point of -252 degrees Celsius: cannot be stored or transported and used as easily as other fuels (which have a higher boiling point)
- Manufactured by cracking heavy petroleum fractions or steam reforming (mixture of steam and methane passed over a catalyst)
- Extracting hydrogen from water is not an economical process on the large scale
- *Uses of Hydrogen:*
    - Fuel in rockets, manufacture of ammonia in Haber Process, manufacture of margarine
- Fuel Cell: device that uses a fuel to react with oxygen in air to produce electrical energy directly
- Fuel cell has two electrodes (carbon or platinum) in contact with electrolyte
    - Negative electrode supplied with hydrogen, positive supplied with oxygen
    - Hydrogen oxidized at negative electrode to release electrons, which flow to the positive electrode, where the oxygen is reduced by absorbing the electrons (and the two ions form water together)
- Fuel cell will not deteriorate chemically (will operate with supply of fuel)
- *Benefits:*
    - Few moving parts, operating in silence and requiring low maintenance
    - More efficient and consume fuel at a rate proportional to electrical load
    - No pollutant emissions since the final product is water

Exam Techniques:

- Only a metal (element/atom) can be described as more or less reactive
- A metal ion/compound must be described as more or less stable