CHEMICAL EQUILIBRIUM

STUDY NOTES

What is Equilibrium?

- Reactions that take place in both the forward and reverse directions simultaneously are called reversible reactions.
- Observable macroscopic changes stop, while microscopic changes continue as reactants change to products, and products change back into reactants.
- When the rate of the forward reaction equals the rate of the reverse reaction, we say a state of dynamic equilibrium has been reached.

Le Chatelier's Principle

*If the conditions of an equilibrium system are changed by changing temperature, pressure or concentration, a process takes place which tends to oppose the effect of the change*

- An equilibrium may be disturbed by changing any one (or more) of the factors for the equilibrium.
  - Temperature
  - Concentration (gases and solutions)
  - Pressure (gases only)

Equilibrium Constant

If we look at the following GENERAL equation

\[ aA + bB \rightleftharpoons cC + dD \]

The expression for the Equilibrium constant – $K_c$ will be as follows:

\[ K_c = \frac{[C]^c [D]^d}{[A]^a [B]^b} \]

If A, B, C or D are solids or pure liquids, they must be LEFT OUT of the $K_c$ expression.

When you answer exam questions do not use the general expression. Write down the $K_c$ expression using the given balanced chemical equation.

- When $K_c$ has a high value, there will be proportionally more of the substance on the product side - we say the equilibrium *lies to the product side* (vice versa for a low value).
- **Only temperature** alters the $K_c$ value for a specific reaction.
- If pressure or concentration is changed, the system adjusts the product and reactant concentrations in such a way that $K_c$ stays exactly the same (on condition the temperature does NOT change).
CHEMICAL EQUILIBRIUM QUESTIONS

Question 1 (Adapted from Nov 2011 Paper 2, Question 7)

1.1 The industrial preparation of hydrogen gas is represented by the equation below.

\[ \text{CH}_4(g) + \text{H}_2\text{O}(g) \rightleftharpoons \text{CO}(g) + 3\text{H}_2(g) \quad \Delta H > 0 \]

The reaction reaches equilibrium at 1 000 °C in a closed container.

1.1.1 State Le Chatelier's principle. (3)

1.1.2 How will an increase in pressure at 1 000 °C (by decreasing the volume) affect the yield of hydrogen gas? Write down only INCREASES, DECREASES OR NO EFFECT. Explain the answer. (3)

1.1.3 Give TWO reasons why high temperatures are used for this reaction. (2)

1.2 Study the reversible reaction represented by the balanced equation below.

\[ \text{H}_2(g) + \text{CO}_2(g) \rightleftharpoons \text{H}_2\text{O}(g) + \text{CO}(g) \]

Initially x moles of H\(_2\)(g) is mixed with 0.3 moles of CO\(_2\)(g) in a sealed 10 dm\(^3\) container. When equilibrium is reached at a certain temperature, it is found that 0.2 moles of H\(_2\)O(g) is present.

The equilibrium constant (K\(_c\)) for the reaction at this temperature is 4.

1.2.1 Calculate the initial number of moles of H\(_2\)(g), x, that was in the container. (8)

1.2.2 The reaction is now carried out at a much higher temperature. It is found that K\(_c\) decreases at this higher temperature.

Is this reaction exothermic or endothermic? Explain the answer. (3)

[19]

Question 2

Consider the following equilibrium reaction:

\[ \text{N}_2(g) + 3 \text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H < 0 \]

9 mol of N\(_2\) and 15 mol of H\(_2\) are pumped into a 500cm\(^3\) container at room temperature. The temperature of the gas mixture is now raised to 405°C resulting in 8 mol NH\(_3\) being present at equilibrium.

Calculate the value of K\(_c\) at 405°C [6]
Question 3
Consider the following reaction:

\[ 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g}) \quad \Delta H < 0 \]

A graph of the AMOUNT of \( \text{SO}_3(\text{g}) \) was plotted against time as shown below:

3.1 How does the rate of the forward reaction compare to the rate of the reverse reaction during the following intervals? (Write down only GREATER THAN, EQUAL TO or LESS THAN.)

3.1.1 OA
3.1.2 BC
3.1.3 DE

3.2 Initially 8,0 moles of \( \text{SO}_2(\text{g}) \) and \( x \) moles of \( \text{O}_2(\text{g}) \) are placed in a 2,0 dm\(^3\) empty container and sealed at a specific temperature. At equilibrium 6,0 moles of \( \text{SO}_3(\text{g}) \) are present in the container. If the \( K_c \) value of the above equilibrium at this temperature is 9, calculate \( x \), that is, the initial amount of \( \text{O}_2(\text{g}) \) that was placed in the container.

3.3 If the changes in the graph from B to D are due to changes in the TEMPERATURE, at which points (B, C or D) will the temperature be the lowest?

3.4 Give an explanation for the answer to 3.3.

3.5 At which point (B, C or D) will the \( K_c \) value be the greatest?

3.6 Give an explanation for the answer to 2.5.

3.7 If the changes in the graph from B to D are due to PRESSURE changes, at which point (B, C or D) will the pressure be the lowest?

3.8 Give an explanation for the answer to 3.7.
ELECTROCHEMISTRY

STUDY NOTES

DIRECT TRANSFER OF ELECTRONS

Example: Zn + CuSO₄ → ZnSO₄ + Cu

Observations: A small Zn plate placed in a blue copper sulphate solution gets covered with a brown precipitate of copper and, eventually, the solution turns clear, and the clear solution is zinc sulphate.

Reaction in ionic form: Zn + Cu²⁺ + SO₄²⁻ → Zn²⁺ + SO₄²⁻ + Cu

Oxidation half: Zn → Zn²⁺ + 2e⁻ (Oxidation is a loss of electrons - OIL)
Reduction half: Cu²⁺ + 2e⁻ → Cu (Reduction is a gain of electron – RIG)

Nett equation: Zn + Cu²⁺ → Zn²⁺ + Cu

THE VOLTAIC OR GALVANIC CELL

Chemical potential energy → Electrical potential energy

Example: Zn/Cu Cell:

Zinc half cell: Zinc electrode placed in a beaker containing a solution of zinc ions
Copper half cell: Copper electrode placed in a beaker containing a solution of copper ions
Salt bridge: Tube filled with ions of a very soluble salt (KNO₃). Completes the internal circuit and maintains electrical neutrality in the electrolyte solutions.
External circuit: Connecting wires that join the Zn electrode to the Cu electrode (can include a voltmeter).

Anode – where oxidation occurs       Cathode – where reductions occurs

Cell Notation: Zn(s) / Zn²⁺(1mol·dm⁻³) // Cu²⁺(1mol·dm⁻³) / Cu(s)

STANDARD ELECTRODE POTENTIALS: THE TABLE

- The Table gives standard Emf values and these values were all measured under standard conditions.
- A reference electrode (standard hydrogen half-cell) was chosen, and all values are measured relative to this.
- Calculate Emf or E⁰ cell using the equation E⁰ cell = E⁰ cathode - E⁰ anode
- E⁰ cell for galvanic cells is positive (spontaneous reactions)
ELECTROLYTIC CELLS

Electrical energy $\rightarrow$ Chemical Reaction

Anode – where oxidation occurs  Cathode – where reductions occurs
$E^0_{\text{cell}}$ for electrolytic cells is negative (non-spontaneous reactions)

Applications:
- Recovering metal from ore (Aluminium from bauxite)
- Refining / purifying gold and copper
- Electroplating
- Production of chlorine in the chlor-alkali industry

EXTRACTION OF ALUMINIUM FROM BAUXITE

Electrolysis of aluminium oxide is hugely environmentally un-friendly. The process uses a very large amount of electricity since the ore needs to be melted.
- The cryolite is added to lower the melting point of the ore.
- Carbon dioxide is formed at the anode of the electrolytic cell. Carbon dioxide is a greenhouse gas and as a result contributes to global warming.
ELECTROCHEMISTRY QUESTIONS

Question 1 (Adapted from Nov 2011 P2 and Feb 2012 P2)

1.1 When a metallic atom becomes an ion, it …

A loses electrons and is oxidised.
B loses electrons and is reduced.
C gains electrons and is oxidised.
D gains electrons and is reduced.        (2)

1.2 The gain of electrons by a substance in a chemical reaction is known as …

A oxidation.
B reduction.
C electrolysis.
D oxidation and reduction.         (2)

1.3 The oxidation number of copper (Cu) in the compound CuSO₄ is ...

A - 2
B - 4
C + 2
D + 4             ( 2 )

1.4 Which ONE of the following statements regarding a copper-silver galvanic cell is TRUE?

A Silver is formed at the anode.
B Copper is formed at the anode.
C Silver is formed at the cathode.
D Copper is formed at the cathode.        (2)

1.5 Consider the two half-reactions below that occur in a battery.

Zn(s) + 2OH⁻(aq) → ZnO(s) + H₂O(l) + 2e⁻
Ag₂O(s) + H₂O(l) +2e⁻ → 2Ag(s) +OH⁻(aq)

Which ONE of the following statements is CORRECT?

A Ag(s) is reduced.
B Zn(s) is the anode.
C Ag₂O(s) is the negative electrode.
D Electrons are transferred from Ag(s) to Zn(s).       (2)
Question 2 (Adapted from Nov 2011, P2, Question 8)

The potential difference of a galvanic cell, measured experimentally by learners, is COMPARED with its potential difference calculated at standard conditions. They set up the galvanic cell shown below.

2.1 Write down the energy conversion that takes place in this cell.  

2.2 State ONE function of the salt bridge.  

2.3 Write down the half-reaction that takes place at the anode.  

2.4 In which direction do electrons flow in the external circuit when this cell delivers a current?  
   Write down only 'from Cu to Pb' or 'from Pb to Cu'.  

2.5 Write down the balanced net (overall) cell reaction.  

2.6 Is the cell reaction exothermic or endothermic?  

2.7 Use the Table of Standard Reduction Potentials to calculate the initial potential difference (emf) of the above cell at STANDARD CONDITIONS  

2.8 From the results obtained the learners conclude that the measured potential difference differs from the calculated potential difference. Give TWO possible reasons for this difference in values.
Question 3 (Adapted from Nov 2011, P2, Question 9)

In the electrolytic cell, represented below, two CARBON RODS are used as electrodes and a concentrated copper(II) chloride solution is used as electrolyte.

![Electrolytic Cell Diagram]

When the cell is functioning, a gas is released at electrode P, whilst electrode Q is coated with a reddish brown layer.

3.1 Define the term electrolyte.  
3.2 Write down a half-reaction to explain the observation made at:
   3.2.1 Electrode P  
   3.2.2 Electrode Q

When the cell is functioning, a gas is released at electrode P, whilst electrode Q is coated with a reddish brown layer.

3.3 Which electrode, P or Q, is the cathode? Give a reason for the answer.

3.4 The carbon rods in the above cell are now replaced with COPPER RODS.

   The following observations are made at electrode P:
   - No gas is released.
   - Its surface appears rough and eroded.

3.4.1 Refer to the RELATIVE STRENGTHS OF REDUCING AGENTS to explain this observation.

3.4.2 This cell can be used for the refining of copper. Which electrode (P or Q) will be replaced with impure copper during the refining process?
CHEMICAL INDUSTRIES

STUDY NOTES

THE CHLOR – ALKALI INDUSTRY

Chlorine is manufactured by the electrolysis of brine (NaCl dissolved in water).

\[ 2\text{NaCl}(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{Cl}_2(\text{g}) + \text{H}_2(\text{g}) + 2\text{NaOH}(\text{aq}) \]

- Sodium hydroxide is produced at the same time as chlorine. We call this a by-product).
- Sodium hydroxide is then used in making soap

There are 3 different types of cells:
1. Mercury cell
2. Diaphragm cell
3. Membrane cell

1. Mercury cell

Image from: http://www.greener-industry.org
• Mercury cell electrolysis, also known as the Castner process, in which the "primary cell", titanium anodes are placed in a sodium (or potassium) chloride solution flowing over a liquid mercury cathode.
• When a potential difference is applied and current flows, chlorine is released at the titanium anode and sodium (or potassium) dissolves in the mercury cathode forming an amalgam.
• The mercury is then recycled to the primary cell.
• The mercury process uses the least energy of the three alternative cells.
• It has the lowest yield of chlorine, of the three main technologies and there are also concerns about mercury emissions. Mercury is a cumulative heavy metal poison.

2. Diaphragm cell

• In this process, a diaphragm separates cathode and anode, preventing the chlorine forming at the anode from re-mixing with the sodium hydroxide and the hydrogen formed at the cathode.
• The brine is continuously fed into the anode compartment and it flows through the diaphragm to the cathode compartment, where the sodium hydroxide is produced.
• This method produces alkali that is quite dilute (about 12%) but diaphragm cells do not have the problem of preventing mercury discharge into the environment.
• They also operate at a lower voltage, resulting in an energy savings but large amounts of steam are required if the sodium hydroxide has to be evaporated to the commercial concentration of 50%, so this then uses more electricity.
3. Membrane cell

- The electrolysis cell is divided into two "rooms" by a cation permeable membrane acting as an ion exchanger.
- Saturated sodium (or potassium) chloride solution is passed through the anode compartment, leaving at a lower concentration.
- Sodium (or potassium) hydroxide solution is circulated through the cathode compartment, exiting at a higher concentration.
- A portion of the concentrated sodium hydroxide solution leaving the cell is diverted as product, while the remainder is diluted with deionised water and passed through the electrolyser again.
- This method is more efficient than the diaphragm cell and produces very pure sodium (or potassium) hydroxide at about 32% concentration, but requires very pure brine.

image from: http://www.drbateman.net
Batteries are GALVANIC (VOLTAIC) cells. They convert chemical energy into electrical energy through a spontaneous Redox reaction.

Cell Capacity - the ability of a fully charged battery to deliver a specific quantity of current over a specific period of time (minutes or hours).

\[ Q = I \Delta t \]

where \( Q \) is measured in Amp. hours (A·h)

Cell emf - gives the voltage that the battery can provide.

- the voltage and charge together gives the amount of energy (work done) the battery can provide.

\[ W = VQ \quad \text{or} \quad W = VI \Delta t \]

Where \( W \) is the work done (energy transferred) and measured in Joules (J)

Primary and Secondary cells

Primary Cells - these are cells that can be discarded after use.

- they become “flat” and therefore, can no longer produce electrical energy required to make an appliance work.

The Leclanche Cell

The very familiar “torch battery” is an example of the Leclanche cell and is a primary cell.

Cathode - is a carbon rod running through the centre of the cell surrounded by a paste of manganese dioxide (MnO₂)

Anode - the zinc metal casing of the cell acts as the anode.

At the anode: \( \text{Zn} \rightarrow \text{Zn}^{2+} + 2e \)

At the cathode: \( 2\text{NH}_4^+ + 2\text{MnO}_2 + 2e \rightarrow \text{Mn}_2\text{O}_3 + \text{H}_2\text{O} + 2\text{NH}_3 \)
Secondary cells

- these are cells that can be recharged by driving a current through them
- this converts electrical energy into chemical energy by reversing the chemical reaction, i.e. the products of the reaction during discharge are reconverted into the starting materials

**The Lead Acid cell (the car battery)**
Anode - lead alloy grids (Pb)
Cathode - grids packed with lead dioxide (PbO₂)
Electrolyte - dilute sulphuric acid (H₂SO₄)

At the anode: \[ \text{Pb} + \text{SO}_4^{2-} \rightarrow \text{PbSO}_4 + 2e \]
At the cathode: \[ \text{PbO}_2 + \text{SO}_4^{2-} + 4\text{H}^+ + 2e \rightarrow \text{PbSO}_4 + 2\text{H}_2\text{O} \]
Overall: \[ \text{Pb} + \text{PbO}_2 + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O} \]

**FERTILISERS**

In order to make fertiliser, we need to manufacture nitric acid, ammonia and sulphuric acid. All of these industrial processes make use of our understanding of equilibrium and rates. Let us investigate these industrial processes further.

**SULPHURIC ACID**

**Uses of sulphuric acid**

- Acts as a drying agent – used by chemical engineers to mop up water.
- Used as an electrolyte in car batteries (lead accumulator batteries).
- Used in the recovery of metals such as uranium and copper.
- Used to clean metal surfaces.
- Used to produce fertilisers.

**THE CONTACT PROCESS**

\[ \text{S (s)} + \text{O}_2 (g) \rightarrow \text{SO}_2 (g) \]
\[ \text{SO}_2 (g) + \text{O}_2 (g) \rightarrow 2 \text{SO}_3 (g) (\text{V}_2\text{O}_5 \text{ catalyst}) \]
\[ \text{SO}_3 (g) + \text{H}_2\text{SO}_4 \rightarrow \text{H}_2\text{S}_2\text{O}_7 \]
\[ \text{H}_2\text{S}_2\text{O}_7 + \text{H}_2\text{O} \rightarrow 2 \text{H}_2\text{SO}_4 \]
- Sulphur is burnt in oxygen.
- Sulphur dioxide is further reacted with oxygen in contact with a vanadium pentoxide catalyst to form sulphur trioxide. This is a reaction that is governed by equilibrium principles.
- Sulphur trioxide is then added to sulphuric acid (note only 1 molecule) to form pyrosulphuric acid/fuming sulphuric acid/oleum.
- Pyrosulphuric acid is mixed with water and sulphuric acid is formed (note 2 molecules).

AMMONIA

Ammonia is produced by means of the Haber process. This process is also governed by equilibrium principles.

HABER PROCESS

\[ N_2 (g) + 3 \text{H}_2 (g) \rightleftharpoons 2 \text{NH}_3 (g) \text{(iron oxide catalyst)} \quad \Delta H = -46 \text{ kJ.mol}^{-1} \]

**Temperature:** Exothermic reaction. Lowering the temperature shifts the equilibrium to the right. However, lower temperature also slows the reaction down so an optimum temperature must be found (600 K - 800 K)

**Pressure:** 4 molecules on the left and 2 molecules on the right; therefore, high pressure favours the forward reaction. (350 atm)

**Concentration:** Ammonia is continuously removed, to reduce ammonia concentration and shift the equilibrium to the right.

Uses of ammonia

- As a cleaning agent when dissolved in water.
- In the manufacture of fertilisers. Ammonium salts are highly soluble in water so they can be dissolved and absorbed by plants, thus making nitrogen available to the plant.
- In the manufacture of ammonium carbonate used in the textile industry.
- In the manufacture of nitric acid.

NITRIC ACID

- Nitric acid is produced by the Ostwald process.

THE OSTWALD PROCESS

\[ 4 \text{NH}_3 (g) + 5 \text{O}_2 (g) \rightarrow 4 \text{NO} (g) + 6 \text{H}_2\text{O} \]
\[ 2 \text{NO} (g) + \text{O}_2 (g) \rightarrow 2 \text{NO}_2 (g) \]
\[ 4 \text{NO}_2 + 2 \text{H}_2\text{O} + \text{O}_2 \rightarrow 4 \text{HNO}_3 \]

- Ammonia is oxidised to nitrogen monoxide and water.
- Nitrogen monoxide is further oxidised to nitrogen dioxide.
- Nitrogen dioxide is then added to water from the first step and oxygen to make nitric acid.
- Nitrate salts are highly soluble in water and, therefore, assist in allowing nitrogen to be absorbed by plants.
THE FERTILISER INDUSTRY

- Commercial fertilisers are described in terms of their relative proportions of nitrogen (N), phosphorus (P) and potassium (K).
- NPK numbers are printed on fertiliser bags.
  E.g. 5:13:5 means the content of the bag is
    - 5% nitrogen
    - 13% phosphorus
    - 5% potassium
- Sources of potassium:
  - Salts containing potassium are referred to as POTASH when used as fertilisers. Mined potassium salts, such as KNO₃ and K₂SO₄ are used.
- Sources of phosphorus:
  - bone meal that was acidified to yield phosphoric acid H₃PO₄
  - mined calcium phosphate Ca₃(PO₄)₂
  - Calcium phosphate is insoluble in water and cannot be absorbed by plants.
- Calcium phosphate is treated with sulphuric acid to yield water soluble superphosphate that can be absorbed.
  \[
  \text{Ca}_3(\text{PO}_4)_2 + \text{H}_2\text{SO}_4 \rightarrow 2\text{CaSO}_4 + \text{Ca(H}_2\text{PO}_4)_2
  \]

CHALLENGES FOR THE CHEMICAL INDUSTRY

- Safety issues regarding the transport of chemicals
- Pollution control
- Waste disposal
- Energy consumption

EUTROPHICATION

- Extensive utilisation of fertilisers leads to pollution of surface and ground water and eutrophication of lakes, dams and rivers. This is mainly due to fertiliser wash off
- Eutrophication is caused by excess phosphates and nitrates in rivers, lakes and dams.
- Phosphates promote the growth of algae which cover the surface of the water and kill aquatic plants below.
- Bacteria decompose the dead aquatic life causing oxygen levels in the water drop to such a low level that aquatic animals suffocate and die.
CHEMICAL INDUSTRIES QUESTIONS

Question 1 (Adapted from Nov 2011, P2, Question 10)

The simplified diagram of a membrane cell used in the chlor-alkali industry is shown below. Gas A, gas B and compound C are the three major products formed during this process. X and Y represent the two electrodes.

1.1 Write down the function of the membrane in this cell. (1)

1.2 Which electrode, X or Y, is connected to the positive terminal of the power supply? Briefly explain how you arrived at the answer. (2)

1.3 Write down the NAME or FORMULA of:
   1.3.1 Gas A (1)
   1.3.2 Gas B (1)
   1.3.3 Compound C (1)

1.4 Write down the balanced net (overall) cell reaction taking place in this cell. (3)

1.5 The chlor-alkali industry is sometimes blamed for contributing to the greenhouse effect. Briefly explain how the above cell contributes to the greenhouse effect. (2)
Question 2  (Adapted from Nov 2011, P2, Question 11)

Nitric acid is used in the preparation of fertiliser. The flow diagram below shows the three steps (A, B and C) in the industrial preparation of nitric acid.

2.1 Write down the following:

2.1.1 Name of this industrial process in the preparation of nitric acid  (1)

2.1.2 Balanced equation for step B  (3)

2.2 NH$_3$(g) reacts with O$_2$(g) to form two products in step A. One of the products is nitrogen(II) oxide. Write down the NAME or FORMULA of the OTHER product.  (1)

2.3 In step C, water is added to the reaction mixture. This step can be represented by the following incomplete equation:

\[ \text{NO}_2(g) + \text{___} + \text{H}_2\text{O}(l) \rightarrow \text{HNO}_3(l) \]

Fill in the missing reactant and balance the equation.  (2)

2.4

A 50 kg bag of fertiliser is labelled as shown in the diagram below.

Calculate the mass of nitrogen present in this bag of fertiliser.  (3)
Question 3 (Adapted from Feb/Mar 2011, P2, Question 10)

A lead-acid battery (car battery) consists of six cells and has a battery capacity of 20 A·h.

The half-reactions that take place in each cell and their respective standard reduction potentials are represented below:

\[ \text{PbSO}_4(s) + \text{H}^+(aq) + 2e^- \rightarrow \text{Pb}(s) + \text{HSO}_4^-(aq) \quad E^\theta = -0.36 \text{ V} \]

\[ \text{PbO}_2(s) + 3\text{H}^+(aq) + \text{HSO}_4^-(aq) + 2e^- \rightarrow \text{PbSO}_4(s) + 2\text{H}_2\text{O}(l) \quad E^\theta = 1.7 \text{ V} \]

3.1 Are car batteries primary or secondary batteries? (1)

3.2 Write down the equation for the net (overall) cell reaction that takes place in each cell of this battery. (3)

3.3 Calculate the emf of the BATTERY, consisting of six cells, under standard conditions. (5)

3.4 Calculate the maximum time that this battery will be able to supply a constant current of 5 A to an appliance connected to it. Assume that the capacity of the battery remains constant. (4)

3.5 State TWO environmental risks associated with the irresponsible disposal of lead-acid batteries. (2)
SOLUTIONS TO ORGANIC MOLECULES & PROPERTIES

Question 1

1.1 A
1.2 D
1.3 C
1.4 C
1.5 B
1.6 B

Question 2 (Adapted from Nov 2011, NSC, P2, Question 3)

2.1
2.1.1 D ✓
2.1.2 C ✓

2.2
2.2.1 4-methylpentanal / 4-metilpentanaal ✓✓
2.2.2 prop-1-yne / prop-1-yn ✓✓
   Accept / Aanvaar:
   propyne / propyn
   1-propyne / 1-propyn

2.3 H₂O / water ✓
   CO₂ / carbon dioxide ✓
   CO₂ / koolstofdioksied / koolsuurgas ✓

2.4
2.4.1 Esters ✓
2.4.2
   \(-\text{C}=-\text{O}=-\text{H}\) ✓

2.4.3 Butanoic acid / Butanoësuur ✓✓
2.4.4
   \(\text{H} \quad \text{H} \quad \text{O} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H}\) ✓✓
Question 3  (Adapted from Nov 2011, NSC, P2, Question

3.1 (Structural) isomers / (Struktuur)isomere ✓ (1)

3.2
3.2.1 Boiling point / Kookpunt ✓ (1)

3.2.2 Branching / Vertakking ✓ (1)

3.3.3 Number of C atoms / Aantal C-atome ✓

**OR/OF**
Molecular or molar mass or molecular formula / C₃H₁₂ ✓
Molekulêre of moëre massa of molekulêre formule / C₃H₁₂ ✓ (1)

3.3 Saturated / Versadig ✓
No carbon-carbon double (or triple) bonds. ✓ ✓
Geen koolstof-koolstofdubbelbindings (of trippelbindings). ✓ ✓

**OR / OF**
Saturated / Versadig ✓
Only single bonds between C atoms. / Slegs enkelbindings tussen C-atome. ✓ ✓

**OR / OF**
Saturated / Versadig ✓
No multiple bonds. / Geen meervoudige bindings. ✓ ✓ (3)

3.4
3.4.1 A ✓ (1)

3.4.2 Pentane / Pentaan ✓ ✓ (2)

3.5.1

```
H--C--H ✓ ✓
   H  H
H--C--C--C--H
   H  H
H--C--H
   H

(2)
```
3.5.2
- Most branching / Molecules most compact or spherical / Smallest surface area (over which intermolecular forces act.).
- Least / Weakest intermolecular forces.
- Least energy needed to overcome intermolecular forces.
- Die meeste vertak, / Molekule mees kompak of sferies / Kleinste oppervlakte (waaroor intermolekulêre kragte werk.)
- Minste / Swakste intermolekulêre kragte.
- Die minste energie benodig om intermolekulêre kragte te oorkom.

3.6
C ✓
Lowest boiling point / Laagste kookpunt

SOLUTIONS TO ORGANIC REACTIONS

Question 1 (Adapted from Nov 2011, P2, Question 5)

1.1
1.1.1 Addition / hydration ✓
Addisie / hidratering / hidrasie ✓

1.1.2 Substitution / Hydrolysis ✓
Substitusie / Hidrolise ✓

1.1.3 Elimination / Dehydrohalogenation / Dehydrobromination ✓
Eliminasie / Dehidrohalogenering / Dehidrobrominering ✓

1.2
\[
\begin{align*}
\text{H} & \quad \text{H} & \quad \text{H} \\
\text{H} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{C} & \quad \text{H} \\
\text{H} & \quad \text{H} & \quad & \quad & \quad & \quad
\end{align*}
\]

\[
\text{H} - \text{C} - \text{C} + \text{HO} - \text{H} / \text{H}_2\text{O} \rightarrow \text{H} - \text{C} - \text{C} - \text{C} - \text{H} \\
\text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H}
\]

1.3
Propan-2-ol
Accept / Aanvaar:
2-propanol

1.4
- Dilute base ✓
Verdunne basis ✓
- Mild heat ✓
Matige hitte ✓
Question 2 (Adapted from Feb/Mar 2011, P2, Question 5.1 & 5.2)

2.1 Prop-1-ene, an UNSATURATED hydrocarbon, and compound X, a SATURATED hydrocarbon, react with chlorine, as represented by the incomplete equations below.

**Reaction I:**

\[
\text{Prop-1-ene} + \text{Cl}_2 \rightarrow
\]

**Reaction II:**

\[
\text{X} + \text{Cl}_2 \rightarrow \text{2-chlorobutane} + \text{Y}
\]

2.1.1 Give a reason why prop-1-ene is classified as unsaturated. (1)

2.1.2 What type of reaction (ADDITION or SUBSTITUTION) takes place in the following:

(a) Reaction I (1)

(b) Reaction II (1)

2.1.3 Write down the structural formula of the product formed in Reaction I. (2)

2.1.4 Write down the reaction condition necessary for Reaction II to take place. (1)

2.1.5 Write down the IUPAC name of reactant X. (1)

2.1.6 Write down the name or formula of product Y. (1)

2.2 2-chlorobutane can either undergo ELIMINATION or SUBSTITUTION in the presence of a strong base such as sodium hydroxide.

2.2.1 Which reaction will preferably take place when 2-chlorobutane is heated in the presence of CONCENTRATED sodium hydroxide in ethanol? Write down only SUBSTITUTION or ELIMINATION. (1)

2.2.2 Write down the IUPAC name of the major organic compound formed in QUESTION 5.2.1. (2)

2.2.3 Use structural formulae to write down a balanced equation for the reaction that takes place when 2-chlorobutane reacts with a DILUTE sodium hydroxide solution. (6)

2.2.4 Write down the name of the type of substitution reaction that takes place in QUESTION 5.2.3. (1)
Question 3 (Adapted from Feb/Mar 2012, P2, Question 5.3)

3 Haloalkanes are used in insecticides (insect killers).

3.1 Write down ONE POSITIVE impact of insecticides on human development. (2)

3.2 Write down ONE NEGATIVE impact of insecticides on humans. (2)

SOLUTIONS TO RATES OF REACTION

Question 1

1.1 a. Exothermic, ✓ heat of the reaction is negative ✓ (2)

b. Endothermic, ✓ heat of the reaction is positive ✓ (2)

1.2 The minimum amount of energy needed to start a reaction ✓ ✓ (2)

1.3 a Has the lowest activation energy ✓ therefore it will have a greater reaction rate ✓ – less energy is needed to start the reaction ✓ (3)

b Has a lower rate of reaction ✓ – more energy is required to get the reaction to take place ✓ (2)

1.4 By adding a catalyst ✓ the amount of activation energy is reduced ✓ (2)

Question 2

2.1 (Gas) syringe / burette / measuring cylinder ✓ (1)

2.2 24 cm³ ✓ ✓ (2)

2.3 Decreases ✓

The gradient of the graph decreases. ✓ (2)

2.4 Catalyst ✓ (1)

2.5 H₂O / water ✓

CuO / copper(II) oxide ✓ (2)

2.6 In terms of lump:
Smaller (exposed) surface area / contact area ✓
Less hydrogen peroxide molecules per unit time comes in contact with the catalyst. ✓

OR/OF

In terms of powder: / In terme van poeier:
Larger (exposed) surface area / contact area ✓
More hydrogen peroxide molecules per unit time comes in contact with the catalyst. ✓ (2)

2.7 Decomposition of hydrogen peroxide releases oxygen ✓ that resists the functioning of the bacteria. / oxidises the bacteria. ✓ (2)
Question 3

3.1.1 The catalyst provides an alternative pathway/route for the reaction with a lower activation energy. More molecules/particles have enough energy and more effective collisions occur, increasing the rate of reaction. (4)

3.1.2 Maxwell-Boltzmann energy distribution curve of particles in a reaction

3.2 At higher temperature, average kinetic energy of molecules increases and the number of effective collisions increases hence the spoiling process goes faster than at lower temperatures. (3)
SOLUTIONS TO CHEMICAL EQUILIBRIUM

Question 1 (Adapted from Nov 2011 Paper 2, Question 7)

1.1.1 When the equilibrium in a closed system is disturbed, the system will shift the equilibrium position OR re-instate a new equilibrium as to OR favour the reaction that will oppose OR cancel OR counteract the change OR disturbance. OR

When a stress / change is placed on a system in equilibrium. The system shifts the equilibrium (position) OR re-instate a new equilibrium so as to remove OR cancel OR oppose the stress / change.

OR

When the conditions affecting an equilibrium are changed, the equilibrium (position) shifts in such a way as to oppose the change OR cancel the change.

1.1.2 Decreases

When the pressure is increased, the reverse reaction is favoured. The reaction that produced the smaller volume/amount of gas is favoured. OR

4 mol or volumes of gas produces 2 mol or volumes of gas.

1.1.3 Products form at faster rate.

Higher yield of products.
1.2.1 Calculations using number of moles

Option 1

\[ n(H_2O) \text{ at equilibrium / by ewewig} = 0.2 \text{ mol (given)} \]
\[ n(H_2O) \text{ formed / gevorm} = n(CO) \text{ formed/gevorm} = 0.2 (\text{mol}) \]
\[ n(H_2) \text{ reacted} = (0.2 \text{ mol}): n(CO}_2 \text{ reacted} = (0.2 \text{ mol}) \]

At equilibrium / By ewewig:
\[ n(H_2) = (x - 0.2)/(x \text{- change / verandering}) \]
\[ n(CO}_2) = 0.1 (\text{mol})/(0.3 \text{- change / verandering}) \]
\[ n(H_2O) = n(CO) = 0.2 (\text{mol}) \]

Equilibrium concentration / Ewewigskonsentrasis:
\[ c(H_2) = \frac{n}{V} = \frac{x - 0.2}{10} \]
\[ c(CO}_2) = \frac{n}{V} = \frac{0.1}{10} \]
\[ c(H_2O) = \frac{n}{V} = \frac{0.2}{10} \]
\[ c(CO) = \frac{n}{V} = \frac{0.2}{10} \]

\[ K_C = \frac{[CO][H_2O]}{[H_2][CO}_2] \]
\[ \therefore \frac{(0.02)(0.02)}{(x - 0.2)(0.01)} = 4 \]
\[ \therefore x = 0.3 \therefore n(H_2) = 0.3 \text{ mol} \]

Option 2

<table>
<thead>
<tr>
<th>Quantity at equilibrium (mol)</th>
<th>H₂</th>
<th>CO₂</th>
<th>H₂O</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial quantity (mol)</td>
<td>x</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aanvangshoeveelheid (mol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change (mol)</td>
<td>-0.2</td>
<td>-0.2</td>
<td>+0.2</td>
<td>+0.2</td>
</tr>
<tr>
<td>Verandering (mol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantity at equilibrium (mol)</td>
<td>x - 0.2</td>
<td>0.1</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Hoeveelheid by ewewig (mol)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equilibrium concentration (mol·dm⁻³)</td>
<td>x - 0.2</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>Ewewigskonsentrasi (mol·dm⁻³)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ K_C = \frac{[CO][H_2O]}{[H_2][CO}_2] \]
\[ \therefore \frac{(0.02)(0.02)}{(x - 0.2)(0.01)} = 4 \]
\[ \therefore x = 0.3 \therefore n(H_2) = 0.3 \text{ mol} \]
Calculations using concentration

<table>
<thead>
<tr>
<th>Initial concentration (mol·dm⁻³)</th>
<th>H₂</th>
<th>CO₂</th>
<th>H₂O</th>
<th>CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aanvangskonsentrasie (mol·dm⁻³)</td>
<td>(\frac{x}{10})</td>
<td>0,03</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Change in concentration (mol·dm⁻³)</td>
<td>0,02</td>
<td>0,02</td>
<td>0,02</td>
<td>0,02</td>
</tr>
<tr>
<td>Equilibrium concentration (mol·dm⁻³)</td>
<td>(\frac{x}{10} - 0,02)</td>
<td>0,01</td>
<td>0,02</td>
<td>0,02</td>
</tr>
</tbody>
</table>

\[K_C = \frac{[CO][H_2O]}{[H_2][CO_2]} \Rightarrow \frac{(0,02)(0,02)}{(0,02 - 0,02)(0,01)} = 4 \Rightarrow \frac{x}{10} = 0,3 \Rightarrow n(H_2) = 0,3 \text{ mol} \quad (8)\]

1.2.2 Exothermic ✓

A decrease in \(K_C\) implies: Lower product concentration / less products OR higher reactant concentration / more reactants. ✓ Reverse reaction favoured. ✓ This means the forward reaction is exothermic.

OR

Exothermic

Decrease in \(K_C\) – reverse reaction is favoured. ✓ Increase in temperature favours the endothermic reaction. ✓ ∴ Forward reaction is exothermic. ✓

Question 2

<table>
<thead>
<tr>
<th>(N_2)</th>
<th>(H_2)</th>
<th>(NH_3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial number of mole (mol)</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>Number of moles used/formed (mol)</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Number of moles at equilibrium (mol)</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Equilibrium concentration (mol·dm⁻³) (c = \frac{n}{V})</td>
<td>(10)✓</td>
<td>(6)✓</td>
</tr>
</tbody>
</table>
\[ K_c = \frac{[\text{NH}_3]^2}{[\text{N}_2][\text{H}_2]^3} \\]

\[ = 16^2 \quad \\frac{1}{(10)(6)^3} \\]

\[ = 0.12 \]  

**Question 3**

3.1.1. greater than √ (1)
3.1.2. less than √ (1)
3.1.3. equal to √ (1)
3.2.

<table>
<thead>
<tr>
<th></th>
<th>SO$_2$</th>
<th>O$_2$</th>
<th>SO$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial number of mole (mol)</td>
<td>8</td>
<td>x</td>
<td>0</td>
</tr>
<tr>
<td>Number of moles used/formed (mol)</td>
<td>6</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Number of moles at equilibrium (mol)</td>
<td>2</td>
<td>x - 3</td>
<td>6</td>
</tr>
<tr>
<td>Equilibrium concentration (mol·dm$^{-3}$) c = n/V</td>
<td>$1^\sqrt{}$</td>
<td>$\frac{x - 3}{2}$</td>
<td>$3^\sqrt{}$</td>
</tr>
</tbody>
</table>

\[ K_c = \frac{[\text{SO}_3]^2}{[\text{O}_2][\text{SO}_2]^2} \\]

\[ 9 = \frac{3^2}{(x-3)(1)^2} \\]

\[ x = 5 \text{ mol} \]  

3.3. B √ (1)
3.4. Forward is exo. √ Exo is favoured at colder temperatures √ (2)
3.5. B √ (1)
3.6. More product √ therefore larger Kc √ (2)
3.7. C √ (1)
3.8. Low pressure favours reverse reaction √ since more gas moles are at reactants side √ (2)

[18]
SOLUTIONS TO ELECTROCHEMISTRY

Question 1

1.1 A
1.2 B
1.3 C
1.4 D
1.5 B

Question 2 (Adapted from Nov 2011, P2, Question 8)

2.1 Chemical (energy) to electrical (energy) ✓
Chemiese (energie) na elektriese (energie) ✓ (1)

2.2 Completes the circuit. / Voltooit die stroombaan. ✓

OR / OF

Maintains electrical neutrality. ✓
Handhaaf elektriese neutraliteit. ✓ (1)

2.3 Pb → Pb^{2+} + 2e^{-} ✓ ✓ (2)

2.4 Pb to Cu ✓ (1)

2.5 Pb + Cu^{2+} ✓ → Pb^{2+} + Cu ✓ Balancing ✓ (3)

2.6 Exothermic / eksotermies ✓ (1)

2.7 \[ E_{\text{cell}}^\circ = E_{\text{cathode}}^\circ - E_{\text{anode}}^\circ \]
\[ = 0,34 \, \text{V} - (-0,13) \]
\[ E_{\text{cell}}^\circ = 0,47 \, \text{V} ✓ \] (4)

2.8 Measurements not done at:
Temperature of 25 °C / 298 K ✓ ✓
Concentration of 1 mol·dm⁻³ ✓ ✓
Question 3 (Adapted from Nov 2011, P2, Question 9)

3.1 A substance that forms free (positive and negative) ions when melted or dissolved. ✓✓
'n Stof wat vrye (positiewe en negatiewe) ione vorm wanneer gesmelt of opgelos word.

OR / OF
A liquid / solution / melted substance that conducts electricity through the movement of free ions. ✓✓
A vloeistof / oplossing / gesmelte stof wat elektrisiteit geleidelik deur die beweging van vrye ione. ✓✓ (2)

3.2
3.2.1 \(2\text{Cl}^- \rightarrow \text{Cl}_2 + 2e^- \)

3.2.2 \(\text{Cu}^{2+} + 2e^- \rightarrow \text{Cu} \)

3.3 Q ✓
Reduction takes place. ✓
Reduksie vind plaas. ✓ (2)

3.4
3.4.1 Cu is a stronger reducing agent ✓ than the Cl⁻ ions. ✓
Cu will be oxidised / loses electrons, ✓
resulting in the plate becoming eroded.

Cu is 'n sterker reduseermiddel ✓ as die Cl⁻-ione. ✓
Cu sal geōksideer word / elektrone verloor, ✓
wat tot gevolg het dat die plaat verweer.

OR / OF
The Cl⁻ ion is a weaker reducing agent ✓ than Cu ✓
and will therefore not be oxidised. ✓

Die Cl⁻-ion is 'n swakker reduseermiddel ✓ as Cu ✓
en sal dus nie geōksideer word nie. (3)

3.4.2 P ✓ (1)
[12]
SOLUTIONS TO CHEMICAL INDUSTRIES

Question 1 (Adapted from Nov 2011, P2, Question 10)

1.1 Allows only positive ions (cations/Na⁺ ions) to migrate to cathode half-cell. ✓

Laat slegs positiewe ione (katione/Na⁺-ione) toe om na die katode-halfsel te migreer. ✓

OR/OF
Prevents chloride ions/Cl⁻ ions from migrating to the cathode half-cell.

Verhoed dat chloried-ione/Cl⁻-ione na die katode-halfsel migreer. (1)

1.2 Y ✓

Chloride ions are oxidised at Y. ✓

Chloriedione word by Y geõksideer. ✓

OR/OF
Chloride ions are negative and must be attracted to Y. ✓

Chloriedione is negatief en word deur Y aangetrek. ✓ (2)

1.3

1.3.1 Hydrogen / H₂ ✓

Waterstof / H₂ ✓ (1)

1.3.2 Chlorine / Cl₂ ✓

Chloor / Cl₂ ✓ (1)

1.3.3 Sodium hydroxide / NaOH ✓

Natriumhidroksied / NaOH ✓ (1)

1.4 2H₂O + 2Cl⁻ → H₂ + 2OH⁻ + Cl₂ ✓ Balancing ✓

OR/OF
2H₂O + 2NaCl → H₂ + 2NaOH + Cl₂ ✓ Balancing ✓ (3)

1.5 Uses huge amounts of electricity / energy. ✓

Combustion of coal during generation of electricity releases huge amounts of carbon dioxide into atmosphere. ✓

Gebruik groot hoeveelhede elektrisiteit. ✓

Verbranding van steenkool tydens opwekking van elektrisiteit stel groot hoeveelhede koolstofdioksied in die atmosfeer vry. ✓ (2)
Question 2 (Adapted from Nov 2011, P2, Question 11)

2.1
2.1.1 Ostwald process / Ostwaldproses ✓

2.1.2 $2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$ ✓ Balancing ✓

2.2 $\text{H}_2\text{O}$ / water ✓

2.3 $4\text{NO}_2 + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 4\text{HNO}_3$ Balancing ✓

2.4

<table>
<thead>
<tr>
<th>Option 1 / Opsie 1</th>
<th>Option 2 / Opsie 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>30% of 50 kg = 15 kg</td>
<td>30% of 50 kg = 15 kg</td>
</tr>
<tr>
<td>( \frac{3}{9} ) \times 15 ✓ = 5 kg ✓</td>
<td>(33,33%) ✓ of 15 ✓ = 5 kg ✓</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Option 3 / Opsie 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \frac{3}{9} ) \times 30 ✓ = 10%</td>
</tr>
<tr>
<td>10% of 50 kg = 5 kg ✓</td>
</tr>
</tbody>
</table>

2.5 ANY ONE / ENIGE EEN:

- Fish / Aquatic life dies. ✓
  Results in loss of income / jobs / food. ✓
  Vis / Waterlewe gaan dood. ✓
  Lei tot verlies aan inkomste / werk / voedsel. ✓

- Leads to poor water quality. ✓
  Not enough drinking water. / Poses health risk. ✓
  Lei tot swak waterkwaliteit. ✓
  Nie genoeg drinkwater nie. / Gesondheidsrisiko. ✓

- Water recreation areas become unattractive / dangerous. ✓
  Lack of income due to decline in tourism. / Less recreation facilities. ✓
  Waterontspanningsareas word onaansienlik/gevaarlik. ✓
  Verlies aan inkomste as gevolg van afname in toerisme. ✓
Question 3 (Adapted from Feb/Mar 2011, P2, Question 10)

A lead-acid battery (car battery) consists of six cells and has a battery capacity of 20 A·h.

The half-reactions that take place in each cell and their respective standard reduction potentials are represented below:

\[
PbSO_4(s) + H^+(aq) + 2e^- \rightarrow Pb(s) + HSO_4^-(aq) \quad E^0 = -0.36 \text{ V}
\]

\[
PbO_2(s) + 3H^+(aq) + HSO_4^-(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l) \quad E^0 = 1.7 \text{ V}
\]

3.1 Are car batteries primary or secondary batteries? (1)

3.2 Write down the equation for the net (overall) cell reaction that takes place in each cell of this battery. (3)

3.3 Calculate the emf of the BATTERY, consisting of six cells, under standard conditions. (5)

3.4 Calculate the maximum time that this battery will be able to supply a constant current of 5 A to an appliance connected to it. Assume that the capacity of the battery remains constant. (4)

3.5 State TWO environmental risks associated with the irresponsible disposal of lead-acid batteries. (2) [15]