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Level: CIE AS and A Level (9701)
Subject: Chemistry
Topic: CIE Chemistry
Type: Mark Scheme


Chemistry CIE AS & A Level
To be used for all exam preparation for 2025+

# CHEMISTRY AS and A

This to be used by all students studying CIE AS and A level Chemistry (9701) But students of other boards may find it useful

## Mark Scheme

**Answer 1.**

a) The reason for the lack of reactivity of the nitrogen molecule is:

- (Due to the) strong N≡N / triple bond; [1 mark]
- $N_2$ is a non-polar molecule; [1 mark]

**[Total: 2 marks]**

- The N ≡ N triple bond has a high bond enthalpy meaning that a large amount of energy is required to break the bond
  - As it is so difficult to break, the $N_2$ molecule is very unreactive and requires extreme conditions to break the bond and allow a nitrogen atom to react
- Electrons are shared equally between the two nitrogen atoms so nitrogen molecules are non-polar
  - This lack of polarity means that nitrogen molecules are not likely to attract or react with other molecules

b)

i) An equation for a possible reaction between nitrogen and oxygen is:

- $N_2 + O_2 \rightarrow 2NO$

OR

$N_2 + 2O_2 \rightarrow 2NO_2$; [1 mark]



ii) **Two** situations, one natural and one as a result of human activities, in which nitrogen and oxygen react together are:

- Natural = In lightning; [1 mark]
- Human activity = In an engine / combustion of fuels (or a specific example); [1 mark]

iii) **Two** main environmental effects of the presence of nitrogen oxides in the atmosphere are:

- Formation of photochemical smog; [1 mark]
- Production of acid rain; [1 mark]

**[Total: 5 marks]**

- Any balanced equation that forms a stable nitrogen oxide would be accepted for part (i)
- For example, the formation of $N_2O$, nitrous oxide:
  - $2N_2 + O_2 \rightarrow 2N_2O$
- You should know the equations for the formation of nitrogen monoxide, NO, and nitrogen dioxide, $NO_2$
- Due to the lack of reactivity of oxygen, nitrogen and oxygen present in the atmosphere will only react under extreme conditions
- Lightning is a natural situation that causes nitrogen and oxygen to react
- The high temperatures and pressures inside car engines (and aeroplane engines) are also extreme enough to cause nitrogen and oxygen to react
- The examples of how oxides of nitrogen are formed given in the mark scheme are the situations that you need to know, but there are other situations where oxides of nitrogen are formed that you would be given credit for, for example:
  - Volcanoes
  - Biological decay
  - Combustion of coal / oil at electric power plants
  - Manufacture of fertilisers

c)

i) The $NO_2$ is removed from the exhaust gases of motor vehicles by:

- A catalytic converter

**OR**

- Passing the exhaust gases over a (hot) catalyst / Pt / Rh; [1 mark]



ii) The equation for this process is:

- $2NO + 2CO \rightarrow N_2 + 2CO_2$; [1 mark]

**[Total: 2 marks]**

- Catalytic converters remove carbon monoxide, nitrogen oxide and nitrogen dioxide from exhaust gases by passing them over a hot catalyst which has a honeycombed structure to increase the surface area
- For nitrogen dioxide:
  - $NO_2 + 2CO \rightarrow ½ N_2 + 2CO_2$
- Both nitrogen monoxide and nitrogen dioxide are reduced

**Answer 2.**

a)

i) The type of compounds that react with nitrogen oxides to form PAN are:

- Unburnt hydrocarbons (from fuel)
  **OR**
  VOCs / volatile organic compounds; [1 mark]

ii) The term photochemical is used to describe smog because:

- Sunlight provides the energy to start the reaction (between nitrogen oxides and unburnt hydrocarbons / VOCs); [1 mark]

**[Total: 2 marks]**

- Nitrogen oxides and unburnt hydrocarbons are both primary pollutants as they are both given off directly into the air from the source of pollution
- Volatile organic compounds, known as VOCs, are mainly made up of unburnt hydrocarbons and the products of oxidation of these hydrocarbons
- VOCs will react with nitrogen oxides in the presence of sunlight to produce peroxyacetyl nitrate or PAN (formula $CH_3CO_3NO_2$) which is a component of photochemical smog
- PAN is a secondary pollutant as it is a pollutant that is not given off directly into the air from human activity
- Photochemical smog tends to be worst in cities in the afternoons of sunny days because:
  - There are a lot of cars emitting VOCs and nitrogen oxides
  - These build up during the day
  - The sunlight provides the necessary energy to start the reaction

b)

i) An equation for the formation of nitric acid from nitrogen dioxide, $NO_2$, in the atmosphere is:

$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$

- Correct formulae; [1 mark]
- Correct balancing; [1 mark]

ii) The role that nitrogen dioxide, $NO_2$, plays in the oxidation of atmospheric sulfur dioxide, $SO_2$, to form acid rain is:

- Catalyst; [1 mark]

**[Total: 3 marks]**

- When $SO_2$, another atmospheric pollutant, is oxidised, it forms $SO_3$ which reacts with rainwater to form dilute sulfuric acid:
  - $SO_3\,(g) + H_2O\,(l) \rightarrow H_2SO_4\,(aq)$
- $NO_2$ catalyses the oxidation of $SO_2$ to $SO_3$:
  - $NO_2\,(g) + SO_2\,(g) \rightarrow SO_3\,(g) + NO\,(g)$
- The formed NO gets oxidised to regenerate $NO_2$:
  - $NO(g) + ½\,O_2(g) \rightarrow NO_2(g)$



c) The oxidation number of nitrogen in nitrogen monoxide, NO, and nitrogen dioxide, $NO_2$ are:

- +2 in NO; [1 mark]
- +4 in $NO_2$; [1 mark]

**[Total: 2 marks]**

- Oxygen has an oxidation number of -2
- Overall, the compounds will have an oxidation number of 0
  - For NO, nitrogen must be +2
  - For $NO_2$, the two oxygen atoms have a combined oxidation number of -4, so nitrogen must have an oxidation number of +4 for the overall oxidation number to be 0

**Answer 3.**

a) Ammonia can be described as a weak base because:

- Ammonia is a proton acceptor; [1 mark]
- That only partially dissociates / ionises in aqueous solution; [1 mark]
- $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$; [1 mark]

**[Total: 3 marks]**

- You must explain why ammonia is considered a base and why it is weak
- **Remember**: Acids are proton donors and bases are proton acceptors
- When in an aqueous solution, ammonia reacts with water to produce ammonium ions and hydroxide ions
- The reaction is reversible and the ⇌ symbol shows that not all the ammonia has reacted to form ammonium ions
  - You will not get the final mark unless you use this reversible symbol
- In fact, only about 1% of the ammonia will react to form ammonium ions so the equilibrium lies well over to the left-hand side

b)

i) The equation for the neutralisation of aqueous ammonia by dilute sulfuric acid is:

- $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$; [1 mark]

ii) The bond angles between N-H bonds in ammonia and the ammonium ion are:

- $NH_3$ = 107°
  **AND**
  $NH_4^+$ = 109.5°; [1 mark]

Explanation:

- $NH_3$ has 3 bonded pairs of electrons and 1 lone pair of electrons
  **AND**
  $NH_4^+$ has 4 bonded pairs of electrons; [1 mark]
- The lone pair of electrons in $NH_3$ pushes the bonded pairs of electrons closer together; [1 mark]

**[Total: 4 marks]**

- When ammonia reacts with an acid, an ammonium salt is formed
- **Remember**: Unlike typical acid-base reactions, no water is produced
- When explaining bond angles or shapes of molecules, it is always important to state the number of bonded pairs and lone pairs of electrons that the central atom has
- 4 bonded pairs of electrons will repel equally giving the tetrahedral shape with a bond angle of 109.5°
- The presence of a lone pair will reduce this angle by 2.5°

c)

i) The equation for the reaction between ammonium chloride and calcium hydroxide is:

$2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O + 2NH_3$

- Correct formulae: [1 mark]
- Correct balancing; [1 mark]

ii) The presence of ammonia gas can be confirmed as:

- Ammonia / it will turn damp red litmus paper blue; [1 mark]

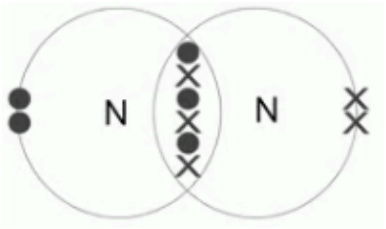
**[Total: 3 marks]**

- As with any acid-base reactions, a salt and water are produced
- In addition, ammonia gas is produced when an ammonium salt is reacted with a base

**Answer 4.**

a)

i) The dot-and-cross diagram of a molecule of nitrogen:




- 3 shared pairs of electrons between two nitrogen atoms; [1 mark]
- 2 non-bonded electrons on each nitrogen atom; [1 mark]

ii) High temperatures are required for oxides of nitrogen to form because:

- Nitrogen is very unreactive; [1 mark]
- (Because) it requires a lot of energy to break the (triple) bond; [1 mark]
- It is a non-polar molecule so is not attracted to other molecules; [1 mark]

**[Total: 5 marks]**

- Each nitrogen atom has 5 electrons, so in order for each atom to gain a full outer shell, it needs to share 3 electrons
  - A triple bond is formed
- After you have drawn the dot-and-cross diagram, ensure you check that each nitrogen atom has 8 electrons!
- High temperatures are needed for nitrogen and oxygen to react, due to the lack of reactivity of nitrogen, so part (ii) is essentially asking you to state and explain the reactivity of nitrogen

b)

i) A possible equation for a reaction between nitrogen and oxygen is:

- $N_2 + O_2 \rightarrow 2NO$
  **OR**
  $N_2 + 2O_2 \rightarrow 2NO_2$; [1 mark]

ii) A possible value for the bond enthalpy of oxygen is:

- A value below 1000 and above 0 kJ $mol^{-1}$; [1 mark]

**[Total: 2 marks]**

- You can give the equation for the formation of either nitrogen monoxide, NO, or nitrogen dioxide, $NO_2$
- The bond enthalpy of oxygen will be less than the bond enthalpy of nitrogen because the nitrogen-nitrogen triple bond will require more energy to break than the oxygen-oxygen double bond
- **Remember:** The value must be positive as bond enthalpies are always endothermic

c)



i) **Two** situations in which nitrogen and oxygen react together are:



- Natural: Lightning; [1 mark]
- As a result of human activity: In an engine / combustion of fuels; [1 mark]

ii) **Two** environmental effects of the presence of nitrogen oxides in the atmosphere are:

- ($NO_x$ produces) acid rain; [1 mark]
- ($NO_x$) forms (photochemical) smog; [1 mark]

**[Total: 4 marks]**

- You could give a specific example of the combustion of fuels
- This can occur in a car engine or in an aeroplane engine

d) The systematic name of $N_2O_5$ is:

- Nitrogen(V) oxide; [1 mark]

**[Total: 1 mark]**

- The are many oxides of nitrogen that exist, some are less stable than others
- The main two oxides of nitrogen that you will come across are nitrogen monoxide, NO, and nitrogen dioxide, $NO_2$
- To give the systematic name, you need to find the oxidation number of nitrogen
  - There are 5 O atoms, each with an oxidation number of -2, so -10 due to oxygen
  - Overall, the oxidation number of the compound is 0
  - The oxidation number of the 2 N atoms combined must be +10, so each N must be +5
- The Roman numeral after nitrogen shows the oxidation number of nitrogen in this compound

**Answer 5.**

a) The meanings of the terms **catalyst** and **homogenous** are:

Catalyst: Any **two** from:

- Speeds up / increases (NOT alters or changes) the rate of a reaction; [1 mark]
- Lowers energy barrier / $E_a$
  **OR**
  Offers a lower energy pathway / mechanism; [1 mark]
- Is not used up or remains unchanged
  **OR**
  Does not alter its mass / concentration
  **OR**
  Does not appear in stoichiometric equation
  **OR**
  Is regenerated; [1 mark]

Homogenous:

- (The catalyst and reactants are) in the same phase / state; [1 mark]

**[Total: 3 marks]**

- **Careful**: You would not be awarded a mark if you said a catalyst alters or changes the rate of reaction as it is not specific enough, you must imply that the rate increases
- These are definitions that you need to invest time in learning as they are easy marks to pick up



b) A major source of nitrogen oxides in the atmosphere, explaining how they are formed is:

- Car exhausts / engines / aeroplanes / lightning / burning fuels / power stations; [1 mark]
- (They are formed as) nitrogen / $N_2$ reacts with oxygen / $O_2$; [1 mark]

**[Total: 2 marks]**

- This is a common question so ensure that you know how nitrogen oxides are formed both naturally and through human activities

c) The equations to describe the chemical role played by nitrogen oxides in the formation of acid rain are:

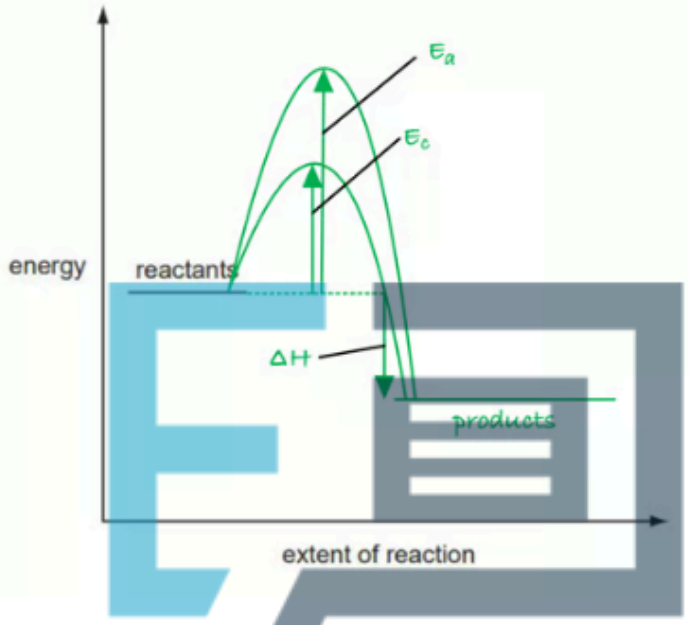
Any **three** from:

- $NO_2 + SO_2 \rightarrow NO + SO_3$; [1 mark]
- $NO + ½\ O2 \rightarrow NO_2$; [1 mark]
- $SO_3 + H_2O \rightarrow H_2SO_4$; [1 mark]
- $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$
  **OR**
  $3NO_2 + H_2O \rightarrow 2HNO_3 + NO$; [1 mark]

**[Total: 3 marks]**

- Nitrogen oxides can form acid rain directly:
  - $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$
- Alternatively, nitrogen oxides can act as a catalyst in the formation of acid rain
- When $SO_2$, another atmospheric pollutant, is oxidised, it forms $SO_3$ which reacts with rainwater to form dilute sulfuric acid:
  - $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$
- $NO_2$ catalyses the oxidation of $SO_2$ to $SO_3$:
  - $NO_2(g) + SO_2(g) \rightarrow SO_3(g) + NO(g)$
- The formed NO gets oxidised to regenerate $NO_2$:
  - $NO(g) + ½\ O_2(g) \rightarrow NO_2(g)$

d) The fully labelled reaction pathway diagram showing the effect of a catalyst on an exothermic reaction is:




- $\Delta H$ shown as negative; [1 mark]
- The catalysed and uncatalysed $E_a$ correctly labelled; [1 mark]
- $E_a > E_c$; [1 mark]

**[Total: 3 marks]**



- If you drew this as an endothermic reaction, i.e. the products higher than the reactants, you could have still scored the final two marks
- Make sure that your arrows are pointing in the correct direction and that you do not use double-headed arrows
- **Careful:** You need to make sure that you draw both the catalysed and uncatalysed reaction pathway diagram in order to show the effect of a catalyst

**Answer 6.**

a)

i) An equation for this process is:

- $N_2 + 3H_2 \rightleftharpoons 2NH_3$; [1 mark]

ii) The **three** usual operating conditions of the Haber process are:

- Pressure: 100 atm or over
  **AND**
  Temperature: 400 - 500°C
  **AND**
  Catalyst: iron; [1 mark]

**[Total: 2 marks]**

- You should know the conditions and equation for the Haber process
- An explanation of the reasons why these conditions are used is a common question that should be answered in terms of the compromises between equilibrium yield, rate of reaction and cost



b) Ammonia can act as a Brønsted–Lowry base because:



- It is able to accept a proton / $H^+$ ion; [1 mark]
- To form the ammonium ion / $NH_4^+$; [1 mark]

**[Total: 2 marks]**

- **Remember**: Acids are proton donors, bases are proton acceptors
- When ammonia accepts a proton, the ammonium ion is formed:
  - $NH_3(aq) + H^+(aq) \rightarrow NH_4^+(aq)$

c)

i) The number of moles of $NH_3$ (g) that were dissolved is:

- Moles $NH_3$ = 1.5 ÷ 24 = 0.0625 (mol); [1 mark]

ii) The equation for the neutralisation of aqueous ammonia by dilute sulfuric acid is:

- $2NH_3 + H_2SO_4 \rightarrow (NH_4)_2SO_4$; [1 mark]

iii) The volume of 0.80 mol $dm^{-3}$ sulfuric acid that is required to neutralise the 300 $cm^3$ of aqueous ammonia is:

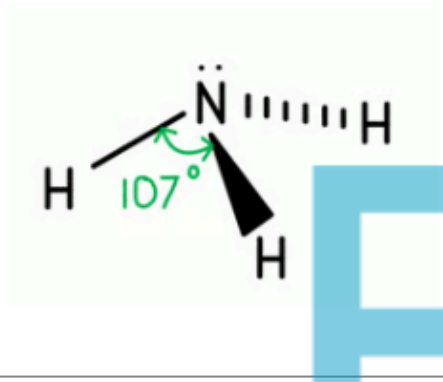
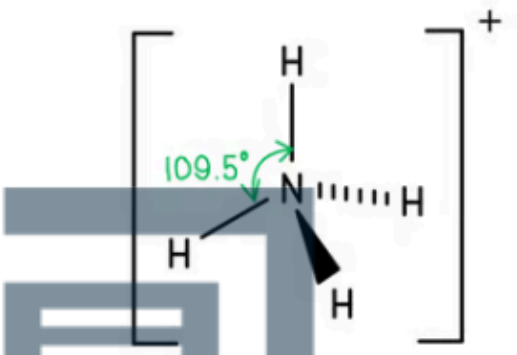
- Moles of $H_2SO_4$ required = 0.03125 (mol); [1 mark]
- Vol of 0.80 mol $dm^{-3}$ $H_2SO_4$ required = (0.03125 x 1000) / 0.80 = 39 / 39.1 ($cm^3$); [1 mark]

**[Total: 4 marks]**

- You need to use the molar gas volume, which is 24.0 $dm^3$ at RTP, to find the number of moles of ammonia
- You are given this value in an exam
- **Remember**: The neutralisation of ammonia and acid produces ammonium salt but NO water
- Use the balanced symbol equation to work out the number of moles of sulfuric acid
- The volume is calculated by moles ÷ conc but this will need to be multiplied by 1000 to give the value in $cm^3$

d)

i) Diagrams to show the shapes of an ammonia molecule and an ammonium ion. and the bond angles:

| | |
|---|---|
|   |   |
| **Ammonia** | **Ammonium ion** |

- Correct diagram of ammonia molecule; [1 mark]
- Correct bond angle of 107° between N–H bonds; [1 mark]
- Correct diagram of ammonium ion; [1 mark]
- Correct bond angle of 109.5° between N–H bonds; [1 mark]

ii) The name of the shapes of an ammonia molecule and an ammonium ion are:

- Ammonia molecule: Pyramidal; [1 mark]
- Ammonium ion: Tetrahedral; [1 mark]



**[Total: 6 marks]**

- Ammonia has a lone pair of electrons which pushes the bonded pairs of electrons together, with a bond angle of 107° and a pyramidal shape
- When ammonium ions are formed, the lone pair of electrons on the ammonia molecule is used to form a dative covalent bond
  - The 4 bonded pairs of electrons repel each other equally giving the ammonium ion a tetrahedral shape with a bond angle of 109.5°

e) The equation for the reaction of ammonium chloride and calcium hydroxide is:

$$2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2H_2O + 2NH_3$$

- Correct reactants and products; [1 mark]
- Correct balancing; [1 mark]

**[Total: 2 marks]**

- Ammonia gas can be prepared from an ammonium salt and a base in an acid-base reaction:
- The salt and base are mixed and then heated
- $NH_4^+$ acts as an acid (proton donor) and $OH^-$ acts as a base (proton acceptor)

**Answer 7.**

a)

i) The equation for this reaction is:

- $N_2 + O_2 \rightarrow 2NO$; [1 mark]

ii) To show that nitrogen has been oxidised:

- The oxidation number of nitrogen has increased from 0 (in $N_2$) to +2 (in NO) (and has therefore been oxidised); [1 mark]



iii) The equation for the further oxidation of nitrogen monoxide is:

- $2NO + O_2 \rightarrow 2NO_2$; [1 mark]

**[Total: 3 marks]**

- You must know the equations for the formation of NO and $NO_2$
- When explaining whether a species has been oxidised or reduced using oxidation numbers, always state what the oxidation number is of the element before and after the reaction
- **Remember**: An increase in oxidation number shows oxidation, and a decrease shows reduction

b) Nitrogen oxides play a role in the formation of photochemical smog by:

- Nitrogen oxides react with unburnt hydrocarbons / VOCs; [1 mark]
- In the presence of light / sunlight; [1 mark]
- Forming PAN / peroxyacetyl nitrate / $CH_3CO_3NO_2$ (found in smog); [1 mark]

**[Total: 3 marks]**

- You do not need to be able to give the equations for this reaction
- PAN is just one of the pollutants found in photochemical smog, you do not need to know any of the other substances
- The reaction is a photochemical reaction as light is needed for it to occur

c) The brown haze associated with photochemical smog is typically worse in cities in the afternoons of hot sunny days because:

- There are more cars, therefore more emissions in cities; [1 mark]
- The volume of PAN / VOCs increases during the day; [1 mark]
- There is lots of (sun)light (energy) present; [1 mark]

**[Total: 3 marks]**

- The 'suggest' command word means that you may not have studied this but you should be able to apply your knowledge to answer it
- There are three marks available, so you need to explain why smog is worse in
  1. cities
  2. afternoons
  3. on hot sunny days

d)

i) The balanced symbol equation for the removal of NO and CO is:

- $2CO + 2NO \rightarrow 2CO_2 + N_2$; [1 mark]

ii) The species acting as the reducing agent in this reaction is:

- Carbon monoxide / CO; [1 mark]
- As it reduces N from +2 (in NO) to 0 (in $N_2$)
  **OR**
  Its oxidation number increases from +2 (in CO) to +4 (in $CO_2$); [1 mark]

**[Total: 3 marks]**

- A reducing agent is one which reduces another species, so is itself oxidised
- You can show which is the reducing agent by either showing, using oxidation numbers, which species is oxidised or that N is reduced

**Answer 8.**

a) An equation to show how $NO_2$ is formed in these situations is:

- $N_2 + 2O_2 \rightarrow 2NO_2$
  **OR**
  $2NO + O_2 \rightarrow 2NO_2$; [1 mark]



**[Total: 1 mark]**

- You can either give the equation to show the formation of nitrogen dioxide from nitrogen and oxygen present in the atmosphere or show the oxidation of nitrogen monoxide

b)

i) $NO_2$ is removed from the exhaust gases of motor vehicles by:

- A catalytic converter
  **AND**
  Passing the exhaust gases over a catalyst / Pt / Rh; [1 mark]

ii) An equation for this process is:

- $NO_2 + 2CO \rightarrow ½ N_2 + 2CO_2$;
  **OR**
  $2NO_2 + CH_4 \rightarrow CO_2 + N_2 + 2H_2O$; [1 mark]

**[Total: 2 marks]**

- **Careful**: Sometimes you just need to state that a catalytic converter is used to remove $NO_2$ from exhaust gases, but other times, such as in this question, you are also required the give the extra detail explaining that the exhaust gases are passed over a catalyst, you are best to give this information just in case!
- The expected equation for this reaction is with carbon monoxide to produce nitrogen and carbon dioxide
  - The other equation is also acceptable although you are not expected to know this



c) Suggesting if $NO_2$ would be reduced if hydrogen was used as a fuel for combustion:



- No, it wouldn't be reduced
  **AND**
  Because the reaction does not require a particular fuel / $NO_2$ is formed from $N_2$ and $O_2$ in air during combustion; [1 mark]

**[Total: 1 mark]**

- You need to give an explanation to gain the mark, just stating it wouldn't be reduced is insufficient
- The fuel used for combustion has no impact on the reaction
- Nitrogen and oxygen used to form nitrogen dioxide both come from the air, not the fuel, and it is the high temperatures found in the combustion engine which allow them to react

d)

i) The environmental significance of this reaction is:

- $SO_3$ produces acid rain; [1 mark]

ii) An equation to show how the $NO_2$ is regenerated in the second step of the oxidation is:

- $NO + ½\ O_2 \rightarrow NO_2$; [1 mark]

iii) The position of the equilibrium:

- Will shift to the right as height increases; [1 mark]
- Because the reaction is exothermic; [1 mark]

**[Total: 4 marks]**

- When $SO_2$ is oxidised, it forms $SO_3$ which reacts with rainwater to form dilute sulfuric acid as follows:
  - $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$
- You need to know both equations which show how $NO_2$ catalyses this reaction
  - $NO_2$ is used in reaction **1** which is the first step and regenerated in the second step
- When explaining how equilibrium is affected with changing conditions, you must always state in which direction equilibrium will shift AND why
- As you move further from the Earth's surface, i.e. height increases, the temperature decreases
- A decrease in temperature will always favour the exothermic reaction, in this case, this is the forward direction, as the $\Delta H$ value is negative
  - The yield of NO and $SO_3$ increases
- The reverse argument would be accepted, i.e. equilibrium shifts to the left as height decreases

**Answer 9.**

a)

i) Ammonia can be prepared from ammonium chloride and calcium hydroxide by:

- Mixing and heating (ammonium chloride and calcium hydroxide); [1 mark]
- Drying (the ammonia) with calcium oxide; [1 mark]

ii) The presence of ammonia gas can be confirmed as:

- It turns damp red litmus paper blue; [1 mark]

**[Total: 3 marks]**

- Ammonium chloride and calcium hydroxide are both solids
- The gas formed in the reaction is typically passed into a U-tube containing calcium oxide, which absorbs any water present
- You should know the test for ammonia gas

b) The reaction between ammonium chloride and calcium hydroxide is an example of an acid-base reaction because:

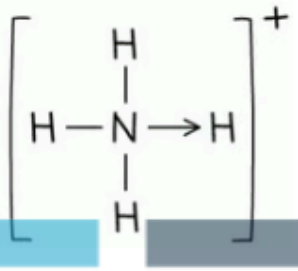
- $NH_4^+$ acts as an acid as it is a proton donor / it donates a proton; [1 mark]
- $OH^-$ acts as a base as it is a proton acceptor / it accepts a proton; [1 mark]

**[Total: 2 mark]**

- You need to identify which species is acting as an acid and as a base and also explain why they are an acid and base in terms of protons

c)

i) A dot-and-cross diagram of the ammonium ion showing all of the bonds within the molecule is:



- Arrow pointing from N to a H atom; [1 mark]
- Rest of structure including square brackets and + charge; [1 mark]

ii) The N-H bonds being the same length means that:

Any **one** from the following:

- All four covalent bonds are equivalent; [1 mark]
- The positive charge is spread evenly around the ion; [1 mark]

**[Total: 3 marks]**

- The ammonium ion has a coordinate bond which is shown by an arrow that points from the atom that is donating the lone pair of electrons (N atom) to the atom that is accepting the lone pair ($H^+$ ion)
- Once the coordinate bond is formed, the bond is indistinguishable from the other bonds

**Answer 10.**

a)

i) Another reason why the nitrogen molecule is so unreactive is:

- It is non-polar; [1 mark]

ii) The type of bonds that exists between the two nitrogen atoms are:

- One σ / sigma bond; [1 mark]
- Two π / pi bonds; [1 mark]

**[Total: 3 marks]**

- As nitrogen is made from two nitrogen atoms, the electrons are shared equally and the molecule is non-polar
- This means that it is not attracted to or likely to react with other molecules
- The triple covalent bond is made from one sigma bond which is due to the end of overlap of hybridised sp orbitals and two pi bonds, due to the sideways overlap of p orbitals
- The two pi orbitals are at right angles to each other

b)

i) **Three** equations to show each of these reactions are:

- Step 1: $N_2(g) + O_2(g) \rightarrow 2NO(g)$; [1 mark]
- Step 2: $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$; [1 mark]
- Step 3: $2NO(g) + H_2O(l) + \frac{1}{2}O_2(g) \rightarrow 2HNO_3(aq)$; [1 mark]

ii) The changes in oxidation number of nitrogen in each reaction and stating if nitrogen is oxidised or reduced in each reaction:

- Step 1: 0 to +2 **AND** oxidation; [1 mark]
- Step 2: +2 to +4 **AND** oxidation; [1 mark]
- Step 3: +4 to +5 **AND** oxidation; [1 mark]

**[Total: 6 marks]**

- Nitrogen in nitrogen(II) oxide has the oxidation +2, as indicated by the Roman numeral
  - Its formula is NO
    - Oxygen has an oxidation number of -2, therefore there must be one nitrogen with an oxidation number of +2 so that the overall oxidation number of the compound is 0
  - It is produced by the reaction between nitrogen and oxygen in the atmosphere
- Nitrogen in nitrogen(IV) oxide has the oxidation +4, as indicated by the Roman numeral
  - Its formula is $NO_2$
    - Oxygen has an oxidation number of -2, therefore there must be two oxygen atoms (2 x -2 = -4) and one nitrogen with an oxidation number of +4 so that the overall oxidation number of the compound is 0
  - It is produced by the reaction between nitrogen(II) oxide and oxygen in the atmosphere
- Nitrogen in nitric acid has the oxidation +5, which you can work out from its formula
  - Its formula is $HNO_3$
    - Oxygen has an oxidation number of -2 and there are 3 oxygen atoms: 3 x -2 = -6
    - Hydrogen has an oxidation number of +1
    - Therefore oxidation number of nitrogen must be +5 so that the overall oxidation number of the compound is 0
  - It is produced by the reaction between nitrogen(II) oxide, water oxygen in the atmosphere
- In each reaction, the oxidation number of nitrogen increases, therefore nitrogen is being oxidised in each reaction

c) The values of *x* and *y* are:

- Moles of $N_xO_y = \frac{120}{24\,000} = 0.005$ (mol); [1 mark]
- $M_r = \frac{\text{mass}}{\text{moles}} = \frac{0.23}{0.005} = 46$ (g mol$^{-1}$); [1 mark]
- $x = 1$ **AND** $y = 2$; [1 mark]

**[Total: 3 marks]**

- To calculate the number of moles of $N_xO_y$, make sure that both the volume of the gas and the molar gas volume are both in either $cm^3$ or $dm^3$, so the calculation is either 120 ÷ 24,000 or 0.12 ÷ 24
- Once you have deduced the $M_r$ of $N_xO_y$, it can be a bit of trial and error to find the number of oxygen and nitrogen atoms:
- You know that it contains at least 1 atom of nitrogen = 14 g mol$^{-1}$ and 1 atom of oxygen = 16 g mol$^{-1}$
  - 14 + 16 = 30
- This leaves 16 g mol$^{-1}$ unaccounted for, which means there must be another oxygen atom
  - 14 + (2 x 16) = 46