SL Paper 3

A student wished to determine the concentration of a solution of sodium hydroxide by titrating it against a 0.100moldm^{-3} aqueous solution of hydrochloric acid.

4.00g of sodium hydroxide pellets were used to make 1.00dm^3 aqueous solution.

20.0cm^3 samples of the sodium hydroxide solution were titrated using bromothymol blue as the indicator.

a. Outline, giving your reasons, how you would carefully prepare the 1.00dm^3 aqueous solution from the 4.00g sodium hydroxide pellets. [2]

b. (i) State the colour change of the indicator that the student would see during his titration using section 22 of the data booklet. [3]

(ii) The student added the acid too quickly. Outline, giving your reason, how this could have affected the calculated concentration.

c. Suggest why, despite preparing the solution and performing the titrations very carefully, widely different results were obtained. [1]

Markscheme

a. *Key Procedural Steps:*

use volumetric flask

mix the solution

fill up to line/mark/«bottom of» meniscus/1 dm^3 «with deionized/distilled water»

Key Technique Aspects:
use balance that reads to two decimal places/use analytical balance/use balance of high precision
mix pellets in beaker with deionized/distilled water «and stir with glass rod to dissolve»
use a funnel «and glass-rod» to avoid loss of solution
need to rinse «the beaker, funnel and glass rod» and transfer washings to the «volumetric» flask

Safety Precautions:
NaOH corrosive/reacts with water exothermically
keep NaOH in dessicator
let the solution cool

Two marks may be awarded from two different categories or from within one category.
*Do **not** accept "use of a funnel to transfer the solid".*
*Do **not** accept "keep volumetric flask in cold water/ice".*

b. (i) blue to green/yellow

(ii) equivalence point has been exceeded
OR
greater volume of/too much acid has been added

«calculated» concentration increased

Accept "end-point" for "equivalence point".

c. colour difficult to detect

OR

using different HCl standards

OR

no significant figures used in subsequent calculation

OR

incorrect method of calculation

Accept any valid hypothesis.

Do not accept any mistakes associated with techniques (based on stem of question) eg. parallax error, not rinsing glassware, etc.

Do not accept "HCl was not standardized".

Accept "reaction of NaOH with CO_2 «from air»".

Accept "NaOH hygroscopic/absorbs moisture/H_2O «from the air/atmosphere»".

Accept "impurities in NaOH".

Accept "temperature changes during experiment".

Ignore a general reference to random errors.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Nitrogen dioxide and sulfur dioxide are two air pollutants.

a. Nitrogen dioxide is formed in a two-stage process. Describe **one** anthropogenic (man-made) source of nitrogen dioxide and state the **two** chemical equations for its formation. [2]

c. Both of these air pollutants also contribute to acid deposition. State **one** chemical equation for **each** gas to describe how each forms an acidic solution. [2]

Markscheme

a. combustion of fuels (at high temperature);

Accept internal combustion/aircraft/jet engines.

$\mathrm{N_2} + \mathrm{O_2} \rightarrow 2\mathrm{NO}$ **and** $2\mathrm{NO} + \mathrm{O_2} \rightarrow 2\mathrm{NO_2}$;

c. $2\mathrm{NO_2} + \mathrm{H_2O} \rightarrow \mathrm{HNO_2} + \mathrm{HNO_3} / 4\mathrm{NO_2} + 2\mathrm{H_2O} + \mathrm{O_2} \rightarrow 4\mathrm{HNO_3}$;

$\mathrm{SO_2} + \mathrm{H_2O} \rightarrow \mathrm{H_2SO_3} / 2\mathrm{SO_2} + 2\mathrm{H_2O} + \mathrm{O_2} \rightarrow 2\mathrm{H_2SO_4}$;

Examiners report

a. The man-made source of nitrogen oxide was generally very well answered, although the equations for its formation proved demanding.

c. The chemical equation for the formation of sulfuric acid was given correctly by many candidates, but it was surprising to see that a significant number of candidates did not know the chemical formula for nitric acid.

Acid deposition is a major environmental concern. Although it is usually associated with human activities, natural sources can also contribute to this phenomenon.

a. State **one** natural origin of acid deposition. [1]

b. State equations which represent chemical transformations of elemental sulfur into sulfurous acid, H_2SO_3. [2]

c. Discuss the possible ways of decreasing acid deposition and its adverse effects on the environment. [4]

Markscheme

a. volcano eruption/activity / lightning / microbial activity;

b. $\mathrm{S} + \mathrm{O_2} \rightarrow \mathrm{SO_2}$;

$\mathrm{SO_2} + \mathrm{H_2O} \rightarrow \mathrm{H_2SO_3}$;

c. washing of coal/natural gas / fluidized bed combustion / remove sulfur before/during the burning;

scrubbing exhaust gases;

using catalytic converters;

low-S diesel / fuel switching / use of alternative energy sources/wind/solar/tidal energy;

reduction in energy consumption;

Accept specific examples of energy saving (e.g. use of bicycles instead of cars).

use lime/formula of a reasonable base on rivers/lakes/soils to neutralize the acid;

Allow other methods/solutions.

*Award **[2 max]** for adverse effects of acid deposition on environment.*

Examiners report

a. This was generally answered well although in (a) some thought the natural acidity of rain, caused by dissolved CO_2, was what was required.

b. Part (b) was answered well (although the number of candidates who wrote elemental sulfur as a diatomic molecule was worrying).

c. There were some good discussions in (c). Many candidates mis-interpreted the question as asking about the effects of acid rain – credit was given.

One major environmental problem that affects many countries is acid rain.

Nitrogen monoxide pollution is a major contributor of acid rain.

a. Explain, writing an appropriate equation, why, even in an unpolluted environment, rainwater is still slightly acidic. [2]

b. (i) Outline the major source of this gas, including an equation. [5]

(ii) Describe, including an equation, a chemical method used to control the emission of this pollutant.

(iii) Identify a compound, to which nitrogen monoxide is eventually converted, that is responsible for acidity in lakes and rivers.

Markscheme

a. dissolved carbon dioxide / $\mathrm{CO_2(g) + H_2O(1) \rightleftharpoons H_2CO_3(aq)}$;

$\mathrm{H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)/CO_2(aq) + H_2O(1) \rightleftharpoons H^+(aq) + HCO_3^-(aq)}$;

b. (i) internal combustion engine / high temperature combustion;

$\mathrm{N_2(g) + O_2(g) \rightarrow 2NO(g)}$;

(ii) catalytic converters / exhaust recirculation;

$\mathrm{2NO(g) + 2CO(g) \rightarrow N_2(g) + 2CO_2(g)}$;

(iii) nitric acid/$\mathrm{HNO_3}$ / nitrous acid/$\mathrm{HNO_2}$;

Examiners report

a. Many candidates identified that dissolved carbon dioxide causes the rain water to be acidic but did not show with the help of equation partial dissociation of carbonic acid.

b. The source of nitrogen monoxide and the method used to control its emission appeared to be well known and many could include appropriate chemical equations. Very few candidates could identify that nitric or nitrous acid is responsible for acidity in lakes and rivers. Some candidates formed $\mathrm{H_2SO_4}$, $\mathrm{H_2SO_3}$, $\mathrm{CH_3COOH}$ and $\mathrm{H_2CO_3}$ from nitrogen monoxide.

Acid deposition is a consequence of industrial processes.

a. State what is meant by the term acid deposition. [1]

b. Industrial processes, such as the burning of coal, generate non-metallic oxides of carbon and nitrogen into the atmosphere. State balanced equations for the reactions by which these oxides are produced and then removed from the atmosphere. [4]

Oxide of carbon:

Produced:

Removed:

Oxide of nitrogen:

Produced:

Removed:

c. All shellfish have a calcium carbonate shell. Discuss, including a balanced equation, the long-term effect of acid deposition on these organisms. [2]

Balanced equation:

Markscheme

a. process by which acidic (substances) leave atmosphere/return to Earth / *OWTTE*;

Do not allow acid rain.

b. *Oxide of carbon*:

Produced: $\mathrm{C(s) + O_2(g) \rightarrow CO_2(g)}$;

Accept a correctly balanced equation for the combustion of a hydrocarbon fuel.

Removed: $\mathrm{CO_2(g) + H_2O(l) \rightarrow H_2CO_3(aq)}$/$\mathrm{6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)}$;

OR

Produced: $\mathrm{2C(s) + O_2(g) \rightarrow 2CO(g)}$;

Removed: $\mathrm{2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)}$/$\mathrm{2CO(g) + O_2 \rightarrow 2CO_2(g)}$;

Oxide of nitrogen:

Produced: $\mathrm{N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)}$/$\mathrm{2NO(g) + O_2(g) \rightarrow 2NO_2(g)}$;

Removed: $\mathrm{2NO_2(g) + H_2O(l) \rightarrow HNO_3(aq) + HNO_2(aq)}$ /

$\mathrm{2H_2O(l) + 4NO_2(g) + O_2(g) \rightarrow 4HNO_3(aq)}$;

OR

Produced: $\mathrm{N_2(g) + O_2(g) \rightarrow 2NO(g)}$;

Removed: $\mathrm{2H_2O(l) + 4NO(g) + O_2(g) \rightarrow 4HNO_2(aq)}$/$\mathrm{2NO(g) + O_2 \rightarrow 2NO_2(g)}$ /

$\mathrm{2CO(g) + 2NO(g) \rightarrow N_2(g) + 2CO_2(g)}$;

Ignore state symbols.

c. shells become thinner as some of the calcium carbonate shell reacts / *OWTTE*;

Accept “dissolving of marine carbonate shells”.

$\mathrm{CaCO_3(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)}$ /

$\mathrm{CO_3^{2-}(s) + 2H^+(aq) \rightarrow CO_2(g) + H_2O(l)}$ /

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

$\mathrm{CaCO_3(s) + H_2SO_4(aq) \rightarrow CaSO_4(aq) + CO_2(g) + H_2O(l)}$;

Ignore state symbols.

Allow equations with H_2SO_3 and HNO_2.

Do not accept H_2CO_3 instead of H_2O and CO_2.

Examiners report

a. Many correct answers. Some candidates oversimplified the term as acid rain.

b. While this question received many correct answers it is worrying that a number of candidates used incorrect formulae for common substances (such as N instead of $\mathrm{N_2}$) and a few did not balance their equations.

c. Most candidates realized that the acid would react with the carbonate rendering the shell weaker and therefore obtained at least one mark. The second mark was scored by a smaller number of candidates. Some candidates lost the second mark by using an acid not found in acid deposition or using the wrong formula for the salt product.

The two major acids that cause acid rain originate from different sources.

a. State an equation that shows why rain water is naturally acidic. [1]

b.i. Outline the process responsible for the production of each acid and state an equation to show its formation. [4]

b.ii Acid rain has caused damage to limestone buildings and marble statues. State an equation to represent the reaction of acid rain with limestone or marble. [1]

Markscheme

a. $\mathrm{CO_2 + H_2O \rightleftharpoons H_2CO_3 / CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-}$;

Do not penalize absence of reversible sign.

Do not accept $CO_2 + H_2O \rightarrow 2H^+ + CO_3^{2-}$.

b.i. *Acid 1:*

$\mathrm{(HNO_2 / HNO_3)}$ high temperature in internal combustion/jet engine;

reaction between $\mathrm{N_2}$ and $\mathrm{O_2}$ at high temperature/lightning;

Accept either of the above for first mark.

$\mathrm{2NO_2 + H_2O \rightarrow HNO_3 + HNO_2 / 4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3}$;

Acid 2:

$\mathrm{(H_2SO_3 / H_2SO_4)}$ from burning of coal / smelting plants / sulfuric acid plants / volcanic activity;

Do not accept combustion of fossil fuels.

$\mathrm{SO_2 + H_2O \rightarrow H_2SO_3 / SO_3 + H_2O \rightarrow H_2SO_4}$;

Allow H_2SO_3/H_2SO_4 to be Acid 1 and HNO_2/HNO_3 to be Acid 2.

b.ii $\mathrm{CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O}$;

Accept equation with H_2SO_3 or H_2SO_4 or ionic equations.

Do not accept equations with H_2CO_3.

Examiners report

a. Most candidates correctly identified carbon dioxide as the source of natural water acidity and wrote an acceptable equation. Many also identified sources of nitric and sulphuric acid, though these equations often proved trickier, with many candidates writing equations for the formation of the oxide from which the acid is derived. Balanced equations for the reaction with limestone also proved to be a challenge, with carbonic acid often appearing as a product.

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Acid deposition can have a significant impact on aquatic environments such as lakes or wetlands.

a.i. State what is meant by the term *acid deposition*. [1]

a.ii. Identify **one** oxide which causes acid deposit [2]

a.iii One effect of acid deposition is to decrease the pH of lake water. Suggest how this effect could be reversed. [1]

Markscheme

a.i. acidic/acid-forming pollutants deposited on the Earth's surface/leave the

atmosphere / rain/precipitation/deposition that is acidic/with a $\mathrm{pH} < 5.6$;

Award mark if two specific examples are given.

a.ii. $SO_2/SO_3/NO_2$;

Allow names of oxides. Do not allow NO_x.

Accept NO, but for second mark $2NO + O_2 \rightarrow 2NO_2$ must also be included.

$\mathrm{SO_2 + H_2O \rightarrow H_2SO_3 / SO_3 + H_2O \rightarrow H_2SO_4 /}$

$\mathrm{2SO_2 + O_2 + 2H_2O \rightarrow 2H_2SO_4 / 2NO_2 + H_2O \rightarrow HNO_2 + HNO_3 /}$

$\mathrm{4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3}$;

Do not allow ECF for equation.

a.iiiaddition of lime/$Ca(OH)_2$/limestone/$CaCO_3$;

Accept "adding alkali/base" or "neutralizing acidity".

Examiners report

a.i. Though the precise definition of "acid deposition" was rarely encountered, most candidates managed a reply that gained them the mark. Even the simple equations required for the reaction of the oxide with water proved difficult for many candidates and, even though most knew how to counteract lake acidity, a disappointing number of students failed to link their method of reducing emissions to the oxide selected, for example mentioning catalytic converters in reference to oxides of sulfur.

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The exhaust gases of automobiles contribute significantly to air pollution in cities.

Outline how the pollutant gases nitrogen(II) oxide, NO, nitrogen(IV) oxide, $\mathrm{NO_2}$ and carbon monoxide, CO, are formed as a result of the action of the internal combustion engine.

NO:

$\mathrm{NO_2}$:

CO:

Markscheme

NO:

$\mathrm{N_2}$ and $\mathrm{O_2}$ react in the engine / $\mathrm{N_2 + O_2 \rightarrow 2NO}$;

No mark for the high temperature without reference to the action between N_2 and O_2.

NO_2:

NO oxidizes/reacts in the air to $\mathrm{NO_2}$ / x;

$\mathrm{2NO + O_2 \rightarrow 2NO_2}$;

CO:

incomplete combustion;

Accept balanced chemical equation for C5–C12 hydrocarbons.

Do not accept C1–C4.

Examiners report

Many candidates identified correctly how the three gases are formed, though some candidates named the reaction of N_2 and O_2 as the source of NO_2 and for incomplete combustion equations with methane and carbon were given.

The normal pH of rainwater is 5.6, but in some parts of the world rainwater has been recorded with a pH of several units lower than this. This is associated with harmful effects on living and non-living things.

a. The decrease in the pH of rainwater is mainly caused by oxides of non-metals, principally nitrogen and sulfur. State chemical equations that show how the primary pollutant nitrogen(II) oxide can produce **two** different acids containing nitrogen. [2]

b. Explain, including an equation, the effect of the acid rain produced in (a) on certain stone buildings. [2]

Markscheme

a. $2NO(g) + O_2(g) \rightarrow 2NO_2(g)$;

$2NO_2(g) + H_2O(l) \rightarrow HNO_2(aq) + HNO_3(aq)$;

Ignore state symbols.

*Award **[1 max]** for $4NO_2(aq) + 2H_2O(l) + O_2(g) \rightarrow 4HNO_3(aq)$.*

b. erosion / buildings of marble/limestone;

$2HNO_3(aq) + CaCO_3(s) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$ /

$2HNO_2(aq) + CaCO_3(s) \rightarrow Ca(NO_2)_2(aq) + H_2O(l) + CO_2(g)$;

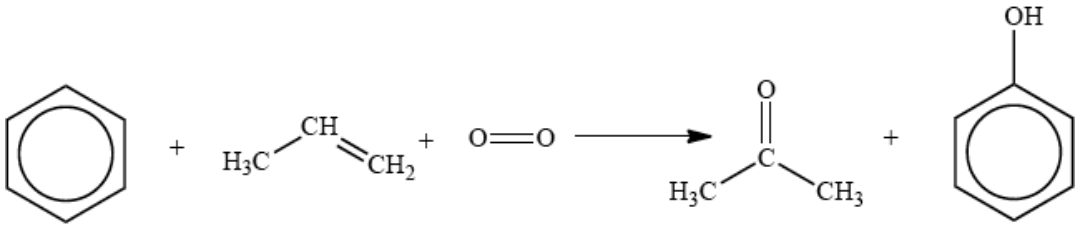
Ignore state symbols.

Examiners report

a. This question was not done well. Few candidates were able to form the two different nitrogen containing acids and the acid used in (b) was generally sulfuric!

b. This question was not done well. Few candidates were able to form the two different nitrogen containing acids and the acid used in (b) was generally sulfuric!

The cumene process is used for the production of both propanone and phenol. The overall reaction is shown in the equation below.



This process is important in the polymer industry. Propanone can be converted into methyl methacrylate, the monomer used to make Perspex®, and phenol is used in phenol-methanal resins, which are important thermosetting plastics.

a.ii. State and explain how the presence of a halogen substituent might affect the acidity of carboxylic acids. [3]

d. Propanone could also be formed from propene by reaction with steam over an acidic catalyst, followed by oxidation of the product. [3]

The reaction of propene with water can yield two possible products. Explain, in terms of the stability of the intermediate carbocations, why one is formed in much greater quantities than the other.

Markscheme

a.ii. halogens make them more acidic;

halogens are electron withdrawing;

Accept halogens (can be) electronegative.

reduces charge on/stabilizes anion formed / weakens O–H bond / makes it easier to lose H^+ ion;

Accept decreases pK_a.

Accept causes anion to be weaker base.

d. one product involves a primary carbocation **and** other a secondary carbocation;

secondary carbocation is more stable (than the primary carbocation, and hence this produces the major product);

alkyl groups reduce charge on carbon atom (through an inductive effect);

Positive inductive effect of alkyl groups alone not enough for M3.

Examiners report

a.ii. (a) (i) was well done by the better candidates only, but most candidates only scored one mark in (ii) and no marks in (iii).

d. (d) was very poorly answered. Some knew that there was an inductive effect but did not understand what this meant, namely that through the positive inductive effect the alkyl groups reduce the charge on the carbon atom.

Nitrogen monoxide gas, NO, is emitted by cars and leads to acid deposition.

Discuss the damage to the environment caused by acid deposition.

Markscheme

leaches/removes nutrients from soil;

Accept specific ions for nutrients.

plant leaves are damaged;

Do not allow just damages plants.

increasing aluminium concentration in the soil;

root damage;

limestone buildings/rocks/statues react with acid;

lakes become acidic killing fish;

toxic metal ions leached/enter into water supplies;

Examiners report

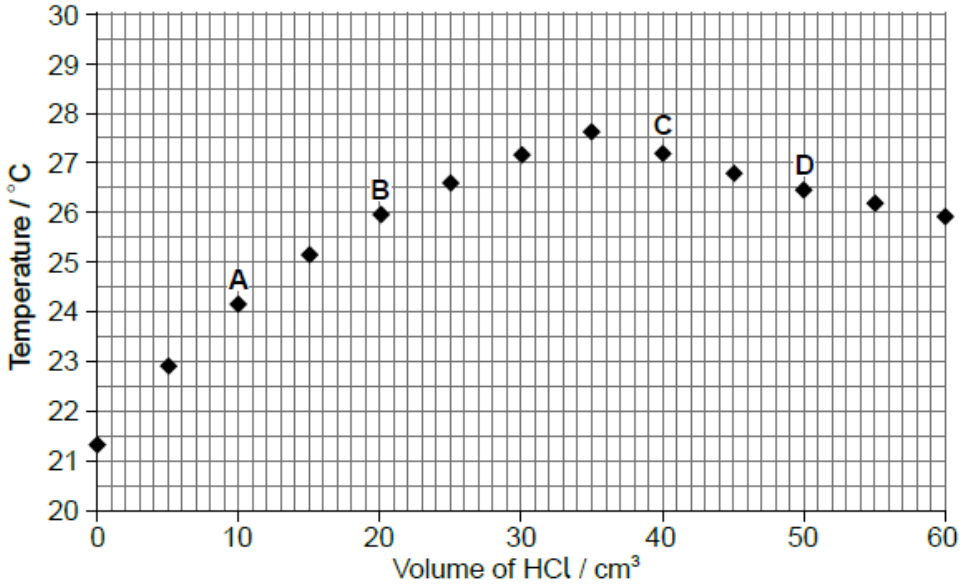
Most candidates gave specific detail in their answer to the effects of acid deposition gaining partial marks, and about a third of the candidates gained full marks on part (a).

A class was determining the concentration of aqueous sodium hydroxide by titrating it with hydrochloric acid, whilst monitoring the pH of the solution. The sodium hydroxide solution was added into a glass beaker from a measuring cylinder and the hydrochloric acid added using a burette. One group of students accidentally used a temperature probe rather than a pH probe. Their results are given below.

Volume of aqueous NaOH = 25.0 ± 0.5 cm^3

Concentration of HCl = 1.00 ± 0.01 mol dm^{-3}

Volume HCl ± 0.1 / cm^3	0.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	55.0	60.0
Temperature ± 0.1 / °C	21.3	22.9	24.2	25.1	25.9	26.6	27.2	27.6	27.2	26.8	26.5	26.2	25.9



a. Deduce why more heat was produced in mixture **B** than in mixture **A**. [1]

b. Deduce why the temperature is higher in mixture **C** than in mixture **D**. [1]

Markscheme

a. more «moles/amount of» acid have been added/reacted

OR

more of the limiting reagent is present

OR

more «of the exothermic» reaction has occurred

[1 mark]

b. no more reaction/same energy released ***AND*** cold/colder/cooler liquid added

OR

no more reaction/same energy released ***AND*** greater total volume of liquid

*Accept "no more reaction/same energy released **AND** greater heat loss «to the surroundings in mixture D»".*

[1 mark]

Examiners report

a. [N/A]
b. [N/A]

Antacids react with hydrochloric acid in the stomach to relieve indigestion. A student investigated different brands of antacid to see which caused the largest increase in pH in a given time. She added the antacids to hydrochloric acid, and recorded the change in pH over five minutes.

Antacid brand	Active ingredient(s)	Recommended dosage	Dose used	Initial pH ±0.02	Final pH ±0.02	Change in pH
A	magnesium hydroxide aluminium hydroxide	2–3 tablets	2 tablets	1.68	4.53	+2.85
B	sodium hydrogen carbonate calcium carbonate	2–4 tablets	2 tablets	1.70	5.31	+3.61
C	calcium carbonate	1–2 tablets	1 tablet	1.70	4.52	+2.82
D	magnesium hydroxide aluminium oxide aluminium hydroxide	1–2 tablets	1 tablet	1.69	2.21	+0.52

a. State an equation for the reaction of magnesium hydroxide with hydrochloric acid. [1]

b. Suggest two variables, besides the time of reaction, which the student should have controlled in the experiment to ensure a fair comparison of the antacids. [2]

c. Calculate the uncertainty in the change in pH. [1]

d. The student concluded that antacid **B** was the most effective, followed by **A** then **C** and finally **D**. Discuss two arguments that reduce the validity of the conclusion. [2]

Markscheme

a. $Mg(OH)_2$ (s) + 2HCl (aq) → $MgCl_2$ (aq) + $2H_2O$ (l)

Accept full or net ionic equation.

b. *Any two from:*

volume «of HCl»

concentration «of HCl»/[HCl]

temperature «of HCl»

mass of antacid/tablets

size of antacid particles/tablets

OR

surface area of antacid «particles»/tablets

Accept "number of tablets/different doses".

*Do **not** accept "same pH meter" **OR** "initial pH" **OR** "concentration of antacid/[antacid]".*

A variable must be given so do not accept answers such as "stirring", "whether tablets are whole or crushed" etc.

[Max 2 Marks]

c. (±) 0.04

OR

(±) 0.03

d. *Any two of:*

uncertainty «(±)0.04/(±)0.03» means **A** and **C** cannot be distinguished

each measurement was conducted once

stomach pH should not be raised a lot «so antacid **B** is not necessarily effective»

mass/number of tablets/dose «of antacid» used was not controlled

actual environment in stomach is different

Accept "amount of tablets" for "dose".

*Do **not** accept "nature/composition of tablets differs".*

Accept an answer such as "time frame is too short since some antacids could be long-acting drugs if they contain a gelatinisation/delaying agent" but not just "time frame is too short since some antacids could be long-acting drugs".

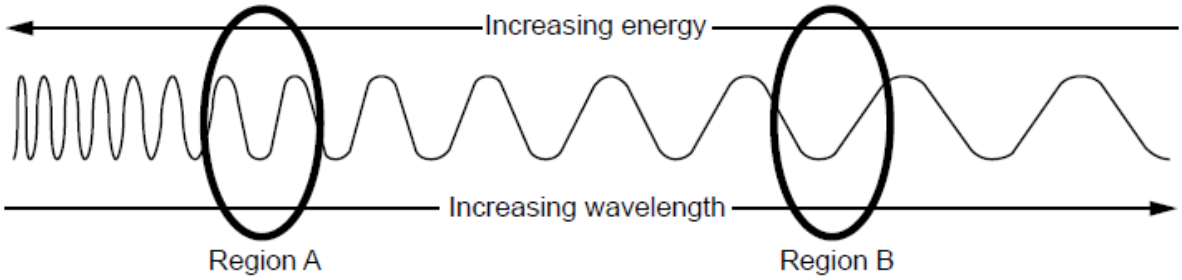
[Max 2 Marks]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

The combustion of fossil fuels produces large amounts of CO_2, a greenhouse gas.

The diagram below illustrates a range of wavelengths in the electromagnetic spectrum.



Synthesis gas, or syngas, mainly composed of CO(g) and H_2(g), is an alternative form of fuel. It can be produced by coal or biomass gasification, passing steam over the source material in a low oxygen environment.

a. Identify which region, **A** or **B**, corresponds to each type of radiation by completing the table. [1]

Type of radiation	Region
Incoming radiation from sun	. . . . .
Re-radiated from Earth's surface	. . . . .
Absorbed by CO_2 in the atmosphere	. . . . .

b.i. Oceans can act as a carbon sink, removing some CO_2(g) from the atmosphere. [1]

$$CO_2(g) \rightleftharpoons CO_2(aq)$$

Aqueous carbon dioxide, CO_2(aq), quickly reacts with ocean water in a new equilibrium reaction. Construct the equilibrium equation for this reaction including state symbols.

b.ii. Describe how large amounts of CO_2 could reduce the pH of the ocean using an equation to support your answer. [2]

c.i. Suggest an equation for the production of syngas from coal. [1]

c.ii. The Fischer-Tropsch process, an indirect coal liquefaction method, converts CO(g) and H_2(g) to larger molecular weight hydrocarbons and steam. [1]

Deduce the equation for the production of octane by this process.

c.iii. Suggest a reason why syngas may be considered a viable alternative to crude oil. [1]

Markscheme

a.

Type of radiation	Region
Incoming radiation from sun	A «and B»
Re-radiated from Earth's surface	B
Absorbed by CO_2 in the atmosphere	B ✓

Accept "B" alone for incoming radiation from sun.

All three correct answers necessary for mark.

[1 mark]

b.i. $CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$

*State symbols **AND** equilibrium arrow required for mark.*

Accept

$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$.

$CO_2(aq) + H_2O(l) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$.

[1 mark]

b.ii. $CO_2(aq) + H_2O(l) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$

OR

$CO_2(aq) + H_2O(l) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$

OR

$H_2CO_3(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + HCO_3^-(aq)$

OR

$H_2CO_3(aq) \rightleftharpoons H^+(aq) + HCO_3^-(aq)$

OR

$H_2CO_3(aq) + 2H_2O(l) \rightleftharpoons 2H_3O^+(aq) + CO_3^{2-}(aq)$

OR

$H_2CO_3(aq) \rightleftharpoons 2H^+(aq) + CO_3^{2-}(aq)$

equilibrium shifts to the right causing increase in $[H_3O^+]/[H^+]$ «thereby decreasing pH»

Equilibrium sign needed in (b) (ii) but penalize missing equilibrium sign once only in b (i) and (ii).

*Do **not** accept "$CO_2(aq) + H_2O(l) \rightleftharpoons H_2CO_3(aq)$" unless equation was not given in b (i).*

[2 marks]

c.i. $C(s) + H_2O(g) \rightarrow CO(g) + H_2(g)$

OR

$3C(s) + H_2O(g) + O_2(g) \rightarrow 3CO(g) + H_2(g)$

OR

$4C(s) + 2H_2O(g) + O_2(g) \rightarrow 4CO(g) + 2H_2(g)$

OR

$5C(s) + H_2O(g) + 2O_2(g) \rightarrow 5CO(g) + H_2(g)$

*Accept other correctly balanced equations which produce both CO **AND** H_2.*

[1 mark]

c.ii. $8CO(g) + 17H_2(g) \rightarrow C_8H_{18}(l) + 8H_2O(g)$

[1 mark]

c.iii. coal more plentiful than crude oil

OR

syngas can be produced from biomass/renewable source

OR

syngas can undergo liquefaction to form octanes/no need to transport crude

OR

syngas can be produced by gasification underground, using carbon

OR

capture/storage «to not release CO_2 to the atmosphere»

OR

coal gasification produces other usable products/slag

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]