

(b) Despite the low reactivity of N_2 , oxides of nitrogen occur in the atmosphere through both natural and man-made processes.

(i) Explain why oxides of nitrogen can be produced by internal combustion engines.

.....
.....
..... [2]

(ii) State and explain, using a suitable equation, how oxides of nitrogen produced by internal combustion engines can be prevented from reaching the atmosphere.

.....
..... [2]

(iv) Suggest an equation to show how NO_2 can contribute **directly** to acid rain.

..... [1]

(c) Explain how the uncontrolled use of nitrate fertilisers on land can lead to a severe reduction in water quality in rivers.

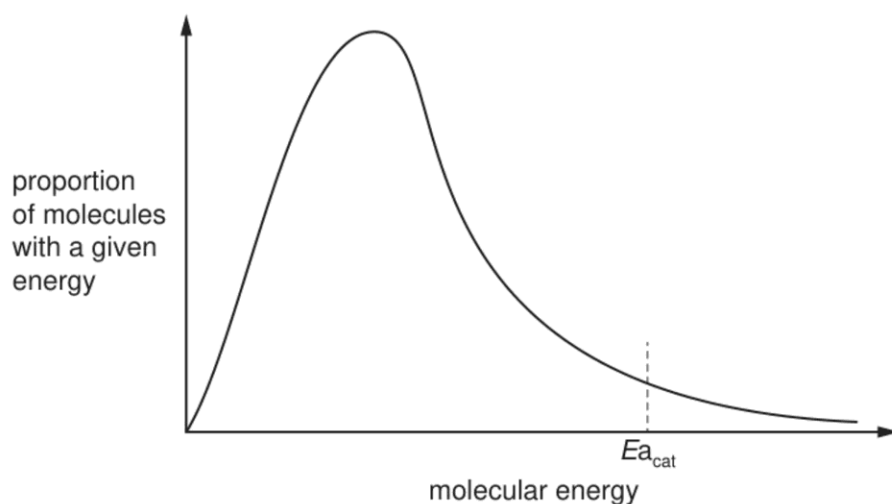
.....
.....
.....
..... [3]

[Total: 13]

- (b) The Contact process is usually carried out at a temperature of approximately 700 K, a pressure of approximately 150 kPa and in the presence of a vanadium(V) oxide catalyst, V_2O_5 .

The Boltzmann distribution for a mixture of SO_2 and O_2 at 700 K is shown.

$E_{a,cat}$ represents the activation energy for the reaction in the presence of the catalyst.



- (i) Add a labelled mark, $E_{a,uncat}$, to the diagram to indicate the activation energy in the absence of the catalyst. [1]

- (iii) State and explain how an increase in pressure would affect both the rate of reaction and the yield of SO_3 in the Contact process.

rate

.....

.....

.....

yield

.....

.....

.....

[4]

- (v) SiH_4 reacts spontaneously with oxygen to produce a white solid and a colourless liquid that turns anhydrous copper(II) sulfate blue. No other products are formed.

Write an equation for the reaction of SiH_4 with oxygen.

State symbols are **not** required.

..... [1]

[Total: 22]

(b) Some bond energies are given.

bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO_3 .

S=O bond energy in SO_3 = kJ mol^{-1} [2]

© UCLES 2018

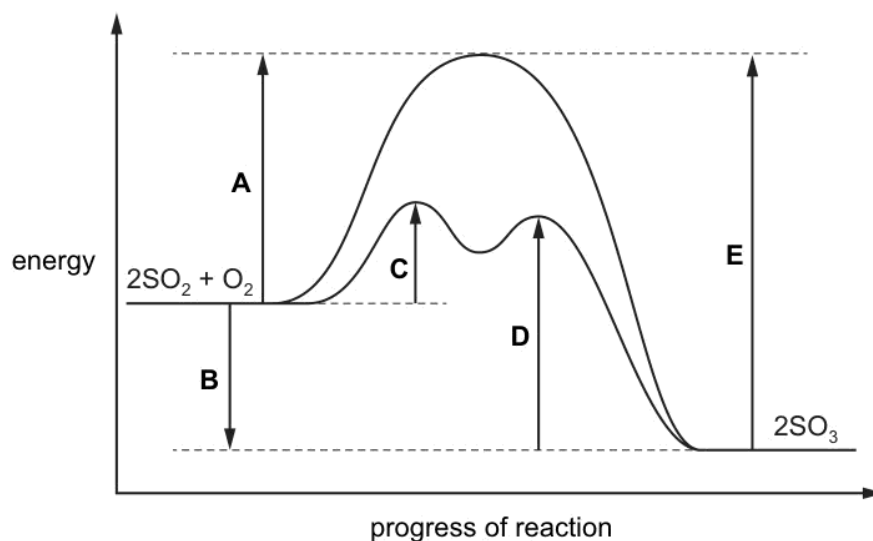
9701/21/M/J/18

3

The Contact process is usually carried out at a temperature of about 400°C and a pressure just above atmospheric pressure. Using a higher or lower temperature and pressure would affect both the rate of production of sulfur trioxide and the yield of sulfur trioxide.

May/June 2018 9701/21 · Q1 (b), (c) (continued ·)

- (c) A reaction pathway diagram for both the catalysed and uncatalysed reactions between SO_2 and O_2 is shown.



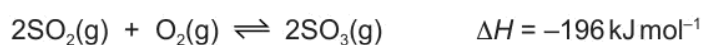
The letters **A–E** represent energy changes.

Complete the table by stating which letter, **A–E**, represents the energy change described.

energy change	letter
the energy change for the production of SO_3	
the activation energy for the production of SO_3 in the absence of a catalyst	
the activation energy for the first step in the decomposition of SO_3 in the presence of a catalyst	

[3]

The equation for this stage of the Contact Process is shown.



May/June 2018 9701/21 · Q1 (b), (c) (cont.)

- (c) Gases produced in internal combustion engines include carbon monoxide, oxides of nitrogen such as NO_2 , and unburnt hydrocarbons.

These gases are removed from the exhaust before they can enter the atmosphere.

- (i) State what is used to remove these gases from the exhaust.

..... [1]

- (ii) Write **one** equation to show how both carbon monoxide, CO , and nitrogen dioxide, NO_2 , are removed from the exhaust.

..... [1]

- (d) Vehicle fuels are treated to remove sulfur. If sulfur is present in a fuel when it is burned, SO_2 is produced and may be released into the atmosphere where it can form acid rain.

- (i) Acid rain can contribute to breathing difficulties.

Identify **two** other consequences of acid rain in the atmosphere.

.....

 [2]

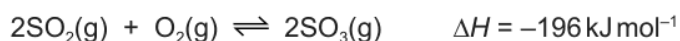
- (ii) NO_2 is involved in the production of acid rain from SO_2 .

Give **two** equations which describe how acid rain is formed by the action of NO_2 with SO_2 .

.....
 [2]

May/June 2018 9701/22 · Q3 (c)(i), (c)(ii), (d)(i), (d)(ii)

- (c) SO_3 is produced by the reaction between SO_2 and O_2 in the Contact process. A dynamic equilibrium is established.



- (i) Explain why increasing the total pressure, at constant temperature, increases the rate of production of SO_3 and increases the yield of SO_3 .

rate

.....

.....

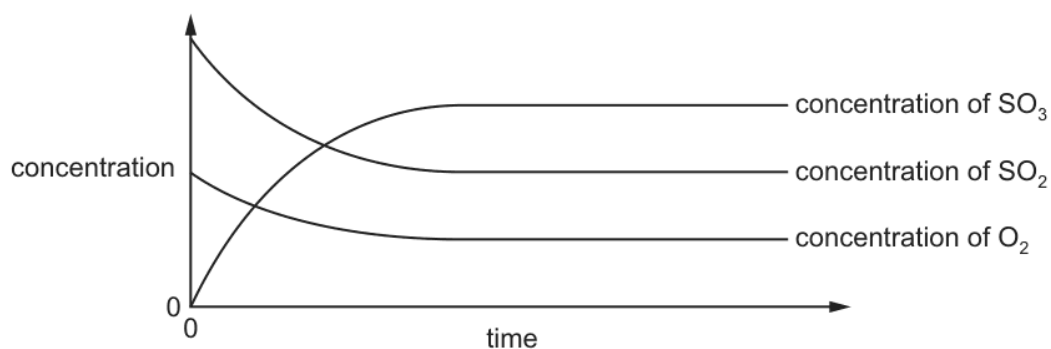
yield

.....

.....

[4]

The graph shows how the concentrations of all three species in the system change with time for a typical reaction mixture. The gradients of all three lines decrease with time and then level off in this dynamic equilibrium.



- (ii) One method of producing NH_3 is by heating ammonium chloride, NH_4Cl , with CaO .



Explain why the reaction of NH_4Cl with CaO produces ammonia.

.....

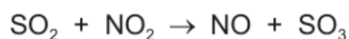
.....

..... [2]

- (a) Explain why high levels of SO_2 may be found in the atmosphere near power stations that burn fossil fuels.

.....
.....
..... [2]

- (b) The SO_2 released can be converted in the atmosphere into sulfuric acid, H_2SO_4 , by reaction with nitrogen dioxide gas, NO_2 , and water, H_2O .



During one year, 1590 tonnes of SO_2 was released into the atmosphere by a fossil-fuel burning power station.

- (i) Use the equations to calculate how many tonnes of H_2SO_4 were formed in the atmosphere. Assume that all of the SO_2 released was converted into H_2SO_4 .

mass of H_2SO_4 = tonnes [2]

- (ii) Describe how NO_2 is also produced by these power stations.

.....
..... [2]

- (iii) State one natural cause of NO_2 being formed in the atmosphere.

..... [1]

May/June 2019 9701/23 · Q4 (a), (b)(i), (b)(ii), (b)(iii)

- (iii) Incomplete combustion of hydrocarbons can release carbon monoxide, CO , into the atmosphere.

Write an equation for the formation of CO from the incomplete combustion of butene, C_4H_8 .

..... [1]

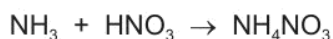
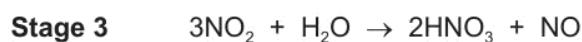
Oct/Nov 2019 9701/21 · Q3 (a)(iii)

- (d) The release of nitrogen monoxide into the atmosphere causes atmospheric pollution.

State and explain the effect of nitrogen monoxide gas in contact with moist air.

.....
..... [2]

- (e) The nitric acid made in stage 3 can then be reacted with ammonia to form ammonium nitrate.



Calculate the volume of nitrogen dioxide, measured at room temperature and pressure, required to make 40 tonnes of ammonium nitrate.

[1 tonne = 1000 kg]

Show your working.

volume of nitrogen dioxide = [3]

- (f) State **one** use of ammonium nitrate.

..... [1]

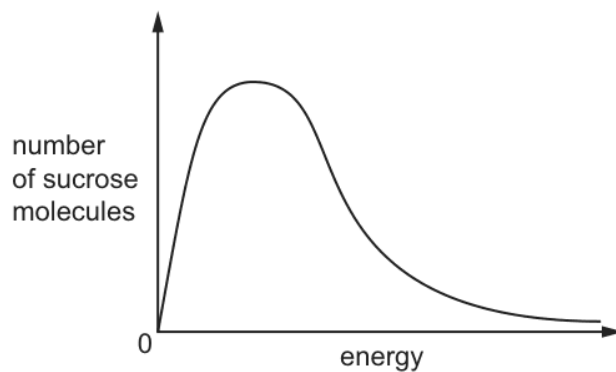
[Total: 12]

6

May/June 2020 9701/22 · Q2 (d), (e), (f) (cont.)

- (ii) If no catalyst is added in reaction **Z**, the reaction is very slow.

Label the Boltzmann distribution to show the effect of adding a catalyst to the sample of sucrose and water molecules at constant temperature.



Explain your labelled diagram.

.....

.....

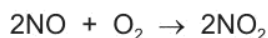
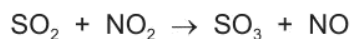
.....

[3]

May/June 2020 9701/23 · Q3 (a)(ii)

- (iii) SO_2 reacts with NO_2 in the atmosphere to form SO_3 and NO .

NO is then oxidised in air to form NO_2 .



State the role of NO_2 in this two-stage process.

..... [1]

© UCLES 2020

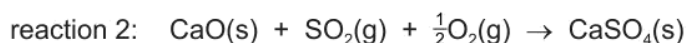
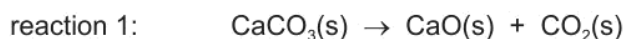
9701/21/O/N/20

[Turn over

4

- (c) Emissions of SO_2 from coal-fired power stations can be reduced by mixing the coal with powdered limestone.

Limestone is heated to form CaO in reaction 1. This then reacts with SO_2 and O_2 to form CaSO_4 in reaction 2.



- (i) State the type of reaction occurring in reaction 1.

..... [1]

Oct/Nov 2020 9701/21 · Q2 (b)(iii), (c)(i)

- (b) Solid ethanedioic acid reacts with aqueous calcium ions to make a precipitate of calcium ethanedioate, CaC_2O_4 .

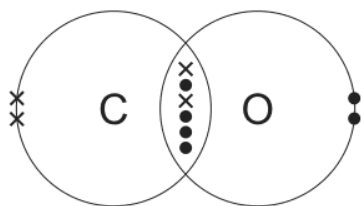
CaC_2O_4 breaks down when heated to form calcium oxide, carbon dioxide and carbon monoxide.

- (i) Construct an equation to represent the reaction of CaC_2O_4 when heated. Include state symbols.

..... [2]

May/June 2021 9701/21 · Q1 (b)(i)

- (a) The diagram shows the arrangement of outer electrons in a molecule of CO(g).



- (i) State **one** similarity and **one** difference in the way the atoms in a carbon monoxide molecule are bonded together compared to the atoms in a nitrogen molecule.

.....
.....
..... [2]

May/June 2021 9701/21 · Q2 (a)(i)

- (e) Polymer **Z** is useful because it absorbs large amounts of water. However, there are problems associated with the disposal of products containing polymer **Z**.

Combustion is not an appropriate method to dispose of pure **Z** because the process releases harmful gases. Some of these gases contribute to the enhanced greenhouse effect.

- (i) Identify a gas released during the combustion of **Z** which contributes to the enhanced greenhouse effect.

..... [1]

- (ii) Identify another gas which could be produced during the combustion of pure **Z**. Describe a consequence, other than the enhanced greenhouse effect, of its release into the atmosphere.

gas

consequence

[1]

[Total: 10]

- (d) The compound As_2S_3 is a common mineral.

When As_2S_3 is heated strongly in air, it forms a mixture of products, as shown.



- (i) A sample containing 0.198 g As_2S_3 is placed in 0.100 dm³ of pure oxygen, an excess, in a reaction chamber connected to a gas syringe at room temperature.

The reactants are heated until no further change is observed. The products are then allowed to cool to room temperature.

Calculate the volume, in dm³, of gas present at the end of the experiment.

The molar volume of gas is 24.0 dm³ mol⁻¹ under these conditions. Assume that the pressure is constant throughout the experiment.

Show your working.

volume of gas remaining = dm³
[4]

- (ii) State the environmental consequences of releasing $\text{SO}_2(\text{g})$ into the atmosphere.

..... [1]

- (iii) $\text{SO}_2(\text{g})$ can be removed from the air by reacting it with $\text{NaOH}(\text{aq})$.

Construct an equation for the reaction of $\text{SO}_2(\text{g})$ with $\text{NaOH}(\text{aq})$. Include state symbols.

..... [2]

[Total: 21]

6

Oct/Nov 2021 9701/21 · Q1 (d)(i), (d)(ii), (d)(iii) (cont.)

- (d) SO_2 and SO_3 are found in the atmosphere.
 The oxidation of SO_2 to SO_3 in the atmosphere is catalysed by NO_2 .
 The first step of the catalytic oxidation is shown in equation 1.



- (i) Construct an equation to show how NO_2 is regenerated in the catalytic oxidation of SO_2 .

..... [1]

March 2022 9701/22 · Q2 (d)(i)

- (ii) In reaction 2, NaCl reacts with concentrated H_2SO_4 to form HCl and NaHSO_4 .
 When NaBr reacts with concentrated H_2SO_4 , the products include Br_2 and SO_2 .

Identify the type(s) of reaction that occur in each case by completing Table 3.1.
 Explain the difference in these reactions.

Table 3.1

reactants	type(s) of reaction
NaCl and concentrated H_2SO_4	
NaBr and concentrated H_2SO_4	

explanation

..... [3]

March 2022 9701/22 · Q3 (b)(ii)

(b) When petrol is burned in an internal combustion engine, oxides of nitrogen are released into the atmosphere. Oxides of nitrogen are responsible for the formation of acid rain.

(i) Suggest the conditions required for the production of oxides of nitrogen during combustion of **M** in an internal combustion engine. Use an appropriate equation in your answer.

.....
.....
.....
..... [2]

(ii) Describe how acid rain is formed in the atmosphere in the presence of oxides of nitrogen and SO_2 . Identify the role of the oxides of nitrogen in this process. Include **all** relevant equations.

.....
.....
.....
..... [3]

(iii) State **one** other type of air pollution that is caused by the production of oxides of nitrogen in an internal combustion engine.

..... [1]

- (b) N_2 can react with oxygen in an internal combustion engine to form a mixture of NO and NO_2 . Fig. 3.1 shows a reaction scheme involving N_2 .

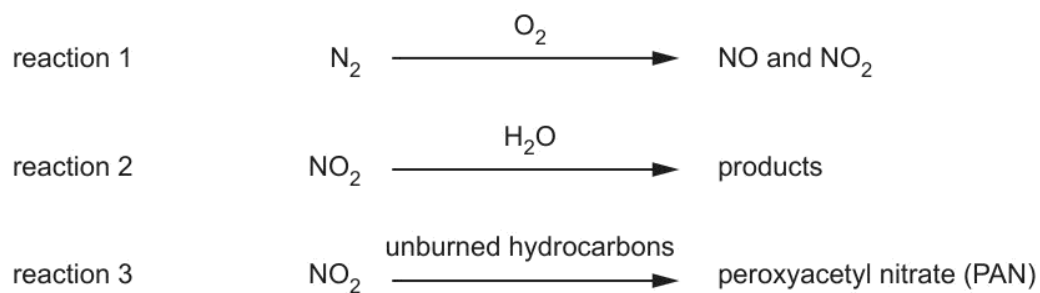


Fig. 3.1

- (i) Write an equation to show the formation of a mixture of NO and NO_2 in reaction 1.
- [1]
- (iii) State and explain the effect, if any, on the **rate** of the Haber process as the pressure is lowered.
-
-
-
- [2]

(c) Separate samples of $\text{CH}_3(\text{CH}_2)_5\text{CHBrCH}_3$, $\text{CH}_3(\text{CH}_2)_5\text{CH}(\text{OH})\text{CH}_3$ and $\text{CH}_3(\text{CH}_2)_5\text{CHCH}_2$ are tested with different reagents.

Complete Table 4.1. If no reaction occurs, write $\times$ in the relevant box.

Table 4.1

reagent added	observation with $\text{CH}_3(\text{CH}_2)_5\text{CHBrCH}_3$	observation with $\text{CH}_3(\text{CH}_2)_5\text{CH}(\text{OH})\text{CH}_3$	observation with $\text{CH}_3(\text{CH}_2)_5\text{CHCH}_2$
$\text{Br}_2(\text{l})$ in the dark			
$\text{PCl}_5(\text{s})$			
$\text{AgNO}_3(\text{aq})$			

[3]



9701/22/M/1/24

(d) When oxides of nitrogen escape into the atmosphere they may be involved in:

- formation of acid rain from sulfur dioxide
- formation of photochemical smog.

(i) Identify the role of NO and NO_2 in the formation of H_2SO_4 from SO_2 in the atmosphere to produce acid rain.

Use relevant equations to support your answer.

.....

.....

.....

.....

.....

..... [3]

(a) Nitrogen is found in inorganic compounds such as nitrogen oxides (NO_x), nitrates and nitric acid.

(i) Identify **one** natural and **one** man-made occurrence of nitrogen oxides in the atmosphere.

natural

man-made

[2]

(ii) Write an equation to describe the role of NO_2 in the direct formation of acid rain.

..... [1]

(iii) Peroxyacetyl nitrate, PAN, is a component of photochemical smog.

Describe how PAN forms from NO_2 .

.....

..... [1]

(iv) Nitric acid reacts with basic oxides to form nitrates.

Write an equation for the reaction of nitric acid with calcium oxide.

..... [1]

(v) Describe what is seen when solid calcium nitrate is heated strongly.

..... [1]

(ii) Identify the species that is oxidised in equation 1.

..... [1]

(iii) NH_3 is a basic gas.

Describe how NH_3 is able to act as a base.

.....

..... [1]

© UCLES 2024



9701/22/O/N/24

8

[Turn over]

(iv) Suggest the shape of the $[\text{Al}(\text{OH})_4]^-$ ion.

..... [1]

- (d) Complete Table 3.1 to show the properties of nitrogen and phosphorus in their standard states.

Table 3.1

	nitrogen	phosphorus
state and appearance of standard state	colourless gas	white solid
electrical conductivity		poor
type of bonding		
type of structure	simple	

[2]

- (e) A form of solid nitrogen has a lattice structure similar to solid iodine.

Identify the type of lattice structure of solid nitrogen.

..... [1]

- (f) At very high temperatures, phosphorus can form P_2 molecules.

P_2 contains a triple bond, $P \equiv P$.

- (i) Describe the formation of the $P \equiv P$ bond in terms of orbital overlap.

.....

 [2]

- (ii) The bond energy of $P \equiv P$ is 485 kJ mol^{-1} . The bond energy of $N \equiv N$ is 944 kJ mol^{-1} . Compare the reactivity of P_2 and N_2 . Explain your answer.

.....

 [1]

[Total: 19]





10

Oct/Nov 2024 9701/22 · Q3 (a)(i), (a)(ii), (a)(iii), (a)(iv), (a)(v), (b)(ii), (b)(iii), (b)(iv), (d), (e), (f)(i), (f)(ii) (cont.)