1

(a) 2,2,4-trimethylpentane

1

(b) 5

1

(c) $C_{20}H_{42} \longrightarrow C_8H_{18} + 2C_3H_6 + 3C_2H_4$

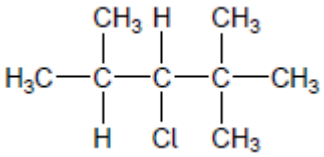
1

(d) Mainly alkenes formed

1

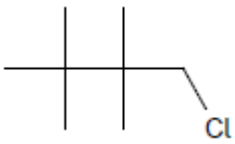
(e) 4 (monochloro isomers)

1



1

(f)



1

(g) $C_8H_{17}{}^{35}Cl = 96.0 + 17.0 + 35.0 = 148.0$
and $C_8H_{17}{}^{37}Cl = 96.0 + 17.0 + 37.0 = 150.0$
Both required

1

M_r of this $C_8H_{17}Cl$ $\frac{(1.5 \times 148.0)}{2.5} + \frac{(1.0 \times 150.0)}{2.5} = 148.8$

1

(h) $\frac{24.6}{12} \quad \frac{2.56}{1} \quad \frac{72.8}{35.5} = 2.05 : 2.56 : 2.05$

Simplest ratio = $\frac{2.05}{2.05} : \frac{2.56}{2.05} : \frac{2.05}{2.05}$

= 1 : 1.25 : 1

1

Whole number ratio (× 4) = 4 : 5 : 4

1

MF = $C_8H_{10}Cl_8$

1

[12]

2 B

[1]

3 C

[1]

4 B

[1]

5 (a) Saturated − single bonds only / no double bonds

1

Hydrocarbon − contains carbon and hydrogen (atoms) only

1

(b) $C_{16}H_{34} + 16.5O_2 \longrightarrow 16CO + 17H_2O$

Allow multiples

1

(c) (On combustion) SO_2 produced

Allow equation to produce SO_2. Ignore sulfur oxides.

1

Which causes acid rain

If formula shown it must be correct

M2 is dependent on M1. But if M1 is sulfur oxides, allow M2.

For M2 allow consequence of acid rain or SO_2.

Ignore greenhouse effect and toxic

1

(d) (i) $C_{16}H_{34} \longrightarrow C_8H_{18} + C_2H_4 + 2C_3H_6$

Allow multiples

1

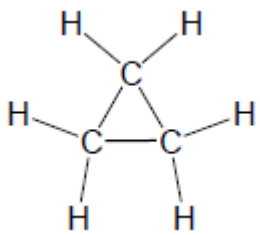
(ii) polypropene / propan(-1 or 2-)ol / propane(-1,2-)diol / isopropanol / propanone / propanal

Accept alternative names

Ignore plastic and polymer

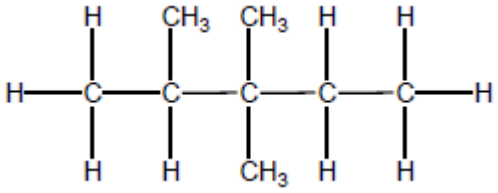
1

(iii)



1

(e)



Allow any unambiguous representation

1

(f) 2,4-dichloro-2,4-dimethylhexane

Only but ignore punctuation

1

[10]

6 (a) (i) **Initiation**

$Br_2 \longrightarrow 2Br\bullet$

First propagation

$Br\bullet + CHF_3 \longrightarrow \bullet CF_3 + HBr$

Second propagation

$Br_2 + \bullet CF_3 \longrightarrow CBrF_3 + Br\bullet$

Termination

$2\bullet CF_3 \longrightarrow C_2F_6$ ***OR*** CF_3CF_3

OR

$2Br\bullet \longrightarrow Br_2$

OR

$Br\bullet + \bullet CF_3 \longrightarrow CBrF_3$

Penalise absence of dot once only

Credit the dot anywhere on the radical

4

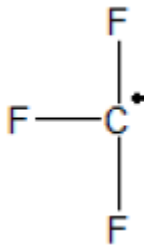
(ii) Ultra-violet / uv / sunlight

OR

T > 100°C OR high temperature

1

(b) (i)



Displayed formula required with the radical dot on carbon

1

(ii) (The) C–Br (bond) breaks more readily / is weaker than (the) C–Cl (bond) (or converse)

OR

The C–Br bond enthalpy / bond strength is less than that for C–Cl (or converse)

*Requires **a comparison** between the two bonds*

Give credit for an answer that suggests that the UV frequency / energy may favour C–Br bond breakage rather than C–Cl bond breakage

Ignore correct references either to size, polarity or electronegativity

Credit correct answers that refer to, for example "the bond between carbon and bromine requires less energy to break than the bond between carbon and chlorine"

1

(iii) **M1**

$Br\bullet + O_3 \longrightarrow BrO\bullet + O_2$

M2

$BrO\bullet + O_3 \longrightarrow Br\bullet + 2O_2$

***M1** and **M2** could be in either order*

Credit the dot anywhere on the radical

Penalise absence of dot once only

Penalise the use of multiples once only

M3 One of the following

They / it / the bromine (atom)

- does not appear in the overall equation
- is regenerated
- is unchanged at the end
- has not been used up
- provides an alternative route / mechanism

3

[10]

7 (a) **P** 3,3−dimethylbut−1−ene

OR

accept 3,3−dimethylbutene

Ignore absence of commas, hyphens and gaps

Require correct spelling

Q 3−chloro−2,2−dimethylbutane

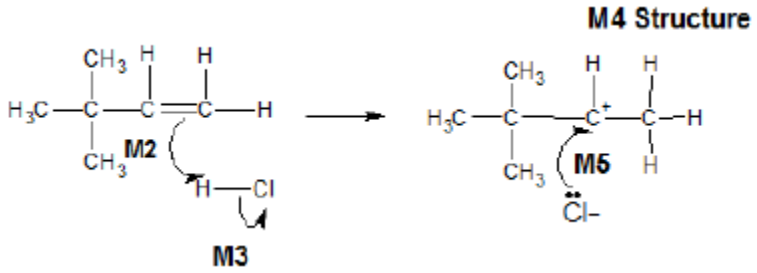
OR

accept 2−chloro−3,3−dimethylbutane

In Q, "chloro" must come before "dimethyl"

2

(b) **M1 Electrophilic addition**



M2 must show an arrow from the double bond towards the H atom of HCl
M3 must show the breaking of the H−Cl bond
M4 is for the structure of the carbocation
M5 must show an arrow from the lone pair of electrons on the negatively charged chloride ion towards the positively charged carbon atom on <u>their</u> carbocation.

NB The arrows here are double−headed

M1 *both words required*

For the mechanism

M3 *Penalise incorrect partial charge on H−Cl bond and penalise formal charges*

Ignore partial negative charge on the double bond.

<u>Maximum 3 of 4 marks for a correct mechanism</u> *using HBr or the wrong organic reactant or wrong organic product (if shown) or a primary carbocation*

Penalise once only in any part of the mechanism for a line and two dots to show a bond

Credit the correct use of "sticks"

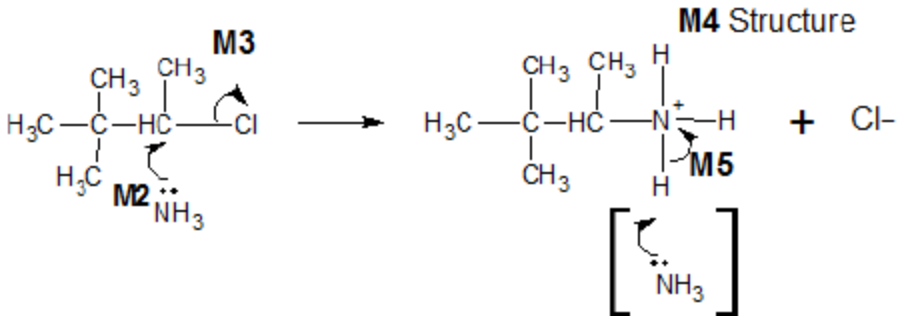
*For **M5**, credit attack on a partially positively charged carbocation structure, but penalise **M4***

5

(c) **M1** **Nucleophilic substitution**

*For **M1**, both words required.*

Accept phonetic spelling



M2 must show an arrow from the lone pair of electrons **on the nitrogen atom** of an ammonia molecule to the correct C atom
M3 must show the movement of a pair of electrons from the C− Cl bond to the Cl atom. Mark **M3** independently provided it is from their original molecule
M4 is for the structure of the alkylammonium ion, which could be a condensed formula. A positive charge **must** be shown on, or close to, the N atom.
M5 is for an arrow from the N−H bond to the N atom
Award full marks for an S_N1 mechanism in which **M2** is the attack of the ammonia on the intermediate carbocation

NB These are double-headed arrows

For the mechanism

*Penalise **M2** if NH_3 is negatively charged.*

*Penalise **M3** for formal charge on C of the C−Cl or incorrect partial charges on C−Cl*

*Penalise **M3** for an additional arrow from the Cl to something else*

*The second mole of ammonia is not essential for **M5**; therefore ignore any species here*

Penalise once only for a line and two dots to show a bond

***Maximum 3 of 4 marks for the mechanism** for wrong organic reactant OR wrong organic product if shown*

Accept the correct use of "sticks"

5

(d) **M1** (base) elimination

***M1** Dehydrohalogenation*

M2 KOH **OR** NaOH

M3 Must be consequential on a correct reagent in **M2**, but if incomplete or inaccurate attempt at reagent (e.g. hydroxide ion), **penalise M2 only and mark on**

Any **one** from

- high temperature OR hot OR heat / boil under reflux
- concentrated
- alcohol / ethanol (as a solvent) / (ethanolic conditions)

***M3** not "reflux" alone*

***M3** if a temperature is stated it must be in the range 78°C to 200 °C*

Ignore "pressure"

3

(e) **M1**

$3NaBr + H_3PO_4 \longrightarrow 3HBr + Na_3PO_4$

***M1** Credit correct ionic species in the equation*

M2 and M3

SO_2 **and** Br_2 identified

M4

Concentrated sulfuric acid

- is an oxidising agent
- oxidises the bromide (ion) or Br^- or NaBr or HBr
- is an electron acceptor

*In **M2** and **M3** the two gases need to be identified. If equations are used using sulfuric acid and the toxic gases are not identified clearly, allow one mark for the formulas of SO_2 and Br_2*

- *apply the list principle as appropriate but ignore any reference to HBr*
- *the marks are for identifying the two gases either by name or formula*

4

[19]

8

(a) Crude oil **OR** petroleum

Not petrol.

1

Fractional distillation / fractionation

Not distillation alone.

1

(b) $C_{12}H_{26} + 12.5O_2 \longrightarrow 12CO + 13H_2O$

Allow balanced equations that produce CO_2 in addition to CO.

Accept multiples.

1

(c) (i) M1 Nitrogen and oxygen (from air) react / combine / allow a correct equation

If nitrogen from petrol / paraffin / impurities CE = 0 / 2.

1

M2 at high temperatures

Allow temperatures above 1000 °C or spark.

Not just heat or hot.

M2 dependent on M1.

But allow 1 mark for nitrogen and oxygen together at high temperatures.

1

(ii) $2NO + O_2 \longrightarrow 2NO_2$

Allow multiples.

1

(iii) $4NO_2 + 2H_2O + O_2 \longrightarrow 4HNO_3$

Allow multiples.

1

(d) (i) C_nH_{2n+2}

Allow C_xH_{2x+2}

CnH2n+2

Allow CxH2x+2

1

(ii) $C_{12}H_{26} \longrightarrow C_6H_{14} + C_6H_{12}$

Only.

1

C_3H_7

Only.

1

Zeolite / aluminosilicate(s)

Ignore aluminium oxide.

1

(iii) Larger molecule / longer carbon chain / more electrons / larger surface area

1

More / stronger van der Waals' forces between molecules

Allow dispersion forces / London forces / temporary induced dipole-dipole forces between molecules.

If breaking bonds, CE = 0 / 2.

1

(e) 2,2,3,3,4,4-hexamethylhexane

Only.

Ignore punctuation.

1

Chain

Ignore branch(ed).

1

(f) Cl_2

Only.

Cl–Cl

Not CL_2 or Cl2 or CL2 or Cl^2 or CL^2.

Ignore Chlorine.

1

[16]

9 (a) (i) **M1** (Compounds / molecules with) the same structural formula

*Penalise **M1** if 'same structure' or 'different structural / displayed formula'.*

M2 with atoms / bonds / groups arranged differently in space

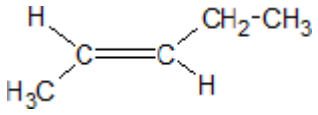
OR atoms / bonds / groups with different spatial arrangements / different orientation

Ignore references to 'same molecular formula' or 'same empirical formula'.

Mark independently.

2

(ii)



Credit C–H_3C

Credit C_2H_5

Penalise C–CH_3CH_2

1

(b) **M1** Br_2 OR bromine (water) OR bromine (in CCl_4 / organic solvent)

*If **M1**, has no reagent or an incorrect reagent, **CE=0**.*

Ignore 'acidified'.

M2 Isomer 1: decolourised / goes colourless / loses its colour

*For **M1** penalise Br (or incorrect formula of other correct reagent), but mark on.*

M3 Isomer 2: remains orange / red / yellow / brown / the same **OR** no reaction / no (observable) change **OR** reference to colour going to the cyclopentane layer

*For **M1**, it must be a whole reagent and / or correct formula.*

*If oxidation state given in name, it must be correct. If 'manganate' OR 'manganate(IV)' or incorrect formula, penalise **M1**, but mark on.*

Alternatives : potassium manganate(VII)

M1 $KMnO_4$ in acid **M2** colourless **M3** purple

M1 $KMnO_4$ in alkali / neutral **M2** brown solid **M3** purple

Credit for the use of **iodine**

M1 iodine (solution / in KI) **M2** colourless **M3** (brown) to purple (credit no change)

Credit for the use of **concentrated H_2SO_4**

M1 concentrated H_2SO_4 **M2** brown **M3** no change / colourless

Ignore 'goes clear'.

Ignore 'nothing (happens)'.

Ignore 'no observation'.

No credit for combustion observations.

3

(c) (i) (Both infrared spectra show an absorption in range) **1620 to 1680** (cm^{-1})

Ignore reference to other ranges (eg for C–H or C–C).

1

(ii) The fingerprint (region) / below 1500 cm^{-1} will be different **or** its fingerprinting will be different

OR

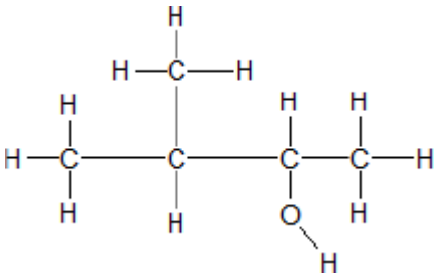
different absorptions / peaks are seen (in the region) below 1500 cm^{-1} (or a specified region within the fingerprint range)

*Allow the words 'dip' **OR** 'spike' **OR** 'low transmittance' as alternatives for absorption.*

QoL

1

(d)



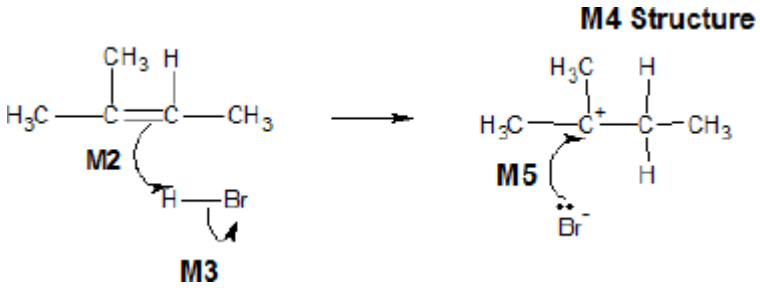
All bonds must be drawn.

Ignore bond angles.

1

(e) (i) **M1 Electrophilic addition**

***M1** both words needed.*



Penalise one mark from <u>their</u> total if half-headed arrows are used.

M2 must show an arrow from the double bond towards the H atom of the H–Br molecule

***M2** Ignore partial negative charge on the double bond.*

M3 must show the breaking of the H–Br bond

***M3** Penalise incorrect partial charges on H–Br bond and penalise formal charges.*

M4 is for the structure of the tertiary carbocation

*Penalise **M4** if there is a bond drawn to the positive charge.*

Penalise once only in any part of the mechanism for a line and two dots to show a bond.

M5 must show an arrow from the lone pair of electrons on the negatively charged bromide ion towards the positively charged carbon atom of either a secondary or a tertiary carbocation

*For **M5**, credit attack on a partially positively charged carbocation structure but penalise **M4**.*

***<u>Max 3 of any 4 marks in the mechanism</u>** for wrong organic reactant or wrong organic product (if shown) or secondary carbocation.*

***<u>Max 2 of any 4 marks in the mechanism</u>** for use of bromine.*

Do not penalise the correct use of 'sticks".

NB The arrows here are double-headed

5

(ii) **M1** Reaction goes via intermediate carbocations / carbonium ions

***M1** is a lower demand mark for knowledge that carbocations are involved.*

M2 (scores both marks and depends on M1)

Tertiary carbocation / carbonium ion is more stable (than the secondary carbocation / carbonium ion)

OR

Secondary carbocation / carbonium ion is less stable (than the tertiary carbocation / carbonium ion)

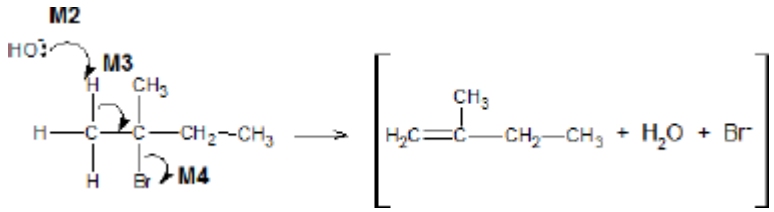
***M2** is of higher demand and requires the idea that the secondary carbocation is less stable or the tertiary carbocation is more stable. Reference to incorrect chemistry is penalised.*

A carbocation may be defined in terms of alkyl groups / number of carbon atoms, rather than formally stated.

2

(f) **M1 Elimination**

M1 *credit 'base elimination' but no other qualifying prefix.*



Penalise one mark from <u>their</u> total if half-headed arrows are used.

M2 must show an arrow from the <u>lone pair on oxygen</u> of a <u>negatively charged hydroxide</u> ion <u>to a correct</u> H atom

*Penalise **M2** if covalent KOH*

M3 must show an arrow from a correct C–H bond adjacent to the C–Br bond to a correct C–C bond. Only award if an arrow is shown attacking the H atom of a correct adjacent C–H bond (in **M2**)

M4 is independent provided it is from their <u>original molecule</u> **BUT penalise M2, M3 and M4 if nucleophilic substitution** shown

Award full marks for an E1 mechanism in which **M2** is on the correct carbocation

NB The arrows here are double-headed

*Penalise **M4** for formal charge on C or Br of the C–Br bond or incorrect partial charges on C–Br.*

*Penalise **M4** if an additional arrow is drawn from the Br of the C–Br bond to, for example, K^+.*

Ignore other partial charges.

*Penalise **once only** in any part of the mechanism for a line and two dots to show a bond.*

***<u>Max 2 of any 3 marks in the mechanism</u>** for wrong reactant <u>or</u> wrong organic product (if shown) <u>or</u> a correct mechanism that leads to the alkene 2-methylbut-2-ene.*

Credit the correct use of "sticks" for the molecule except for the C–H being attacked.

M5 hydroxide ion behaves as a <u>base</u> / <u>proton acceptor</u> / <u>electron pair donor</u> / <u>lone pair donor</u>

*Penalise **M5** if 'nucleophile'.*

5

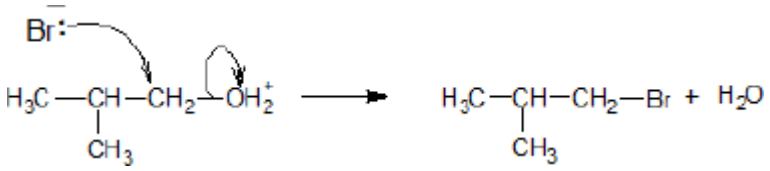
[21]

10 (a) (i) **M1** double-headed curly arrow from the lone pair of the bromide ion to the C atom of the CH_2

Penalise additional arrows.

M2 double-headed arrow from the bond to the O atom

As follows



2

(ii) **M1** nucleophilic substitution

***M1** both words needed (allow phonetic spelling).*

M2 1-bromo(-2-)methylpropane

***M2** Require correct spelling in the name but ignore any hyphens or commas.*

2

(b) **M1** hydrolysis

*For **M1** give credit for 'hydration' on this occasion only.*

M2 C≡N with absorption range 2220–2260 (cm^{-1})

*Credit 1 mark from **M2** and **M3** for identifying C≡N **and** either O–H(acids) **or** C=O **or** C–O without reference to wavenumbers or with incorrect wavenumbers.*

M3 O–H(acids) with absorption range 2500–3000 (cm^{-1})

OR

C=O with absorption range 1680–1750 (cm^{-1})

OR

C–O with absorption range 1000–1300 (cm^{-1})

*Apply the list principle to **M3***

3

(c) (i) **M1** Yield / product **OR** ester increases / goes up / gets more

M2 (By Le Chatelier's principle) the position of equilibrium is driven / shifts / moves to the right / L to R / in the forward direction / to the product(s)

M3 – requires a correct statement in M2

(The position of equilibrium moves)

to oppose the increased concentration of ethanol

to oppose the increased moles of ethanol

to lower the concentration of ethanol

to oppose the change and decrease the ethanol

*If no reference to **M1**, marks **M2** and **M3** can still score BUT if **M1** is incorrect CE=0*

*If there is reference to 'pressure' award **M1** ONLY.*

3

(ii) **M1**

Catalysts provide an alternative route / pathway / mechanism

OR

surface adsorption / surface reaction occurs

*For **M1**, not simply 'provides a surface' as the only statement.*

***M1** may be scored by reference to a specific example.*

M2

that has a lower / reduced activation energy

OR

lowers / reduces the activation energy

*Penalise **M2** for reference to an increase in the energy of the molecules.*

*For **M2**, the student may use a definition of activation energy without referring to the term.*

*Reference to an increase in successful collisions in unit time alone is not sufficient for **M2** since it does not explain why this has occurred.*

2

[12]