

**Q26.**

Oxygen and ozone (O<sub>3</sub>) both occur as gases in the upper atmosphere.

Chlorine atoms catalyse the decomposition of ozone and contribute to the formation of a hole in the ozone layer.

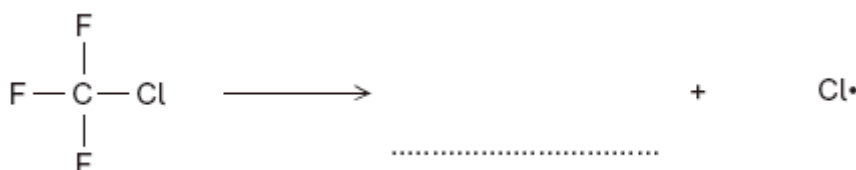
These chlorine atoms are formed from chlorofluorocarbons (CFCs) such as CF<sub>3</sub>Cl

- (a) (i) Give the IUPAC name of CF<sub>3</sub>Cl

\_\_\_\_\_

(1)

- (ii) Complete the following equation that shows the formation of a chlorine atom from a molecule of CF<sub>3</sub>Cl



(1)

- (iii) State what the • represents in Cl•

\_\_\_\_\_

(1)

- (b) Write two equations that show how chlorine atoms catalyse the decomposition of ozone into oxygen.

Equation 1 \_\_\_\_\_

Equation 2 \_\_\_\_\_

(2)

- (c) An equilibrium is established between oxygen and ozone molecules as shown below.



- (i) State Le Chatelier's principle.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(1)



- (ii) Use Le Chatelier's principle to explain how an increase in temperature causes an increase in the equilibrium yield of ozone.

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(2)

- (d) Chemists supported the legislation to ban the use of CFCs. Modern refrigerators use pentane rather than CFCs as refrigerants. With reference to its formula, state why pentane is a more environmentally acceptable refrigerant.

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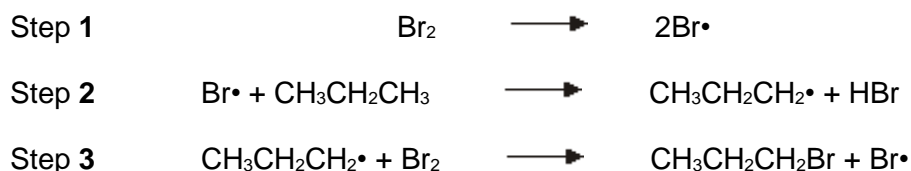
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(1)

(Total 9 marks)

### Q27.

- (a) The reaction of bromine with propane is similar to that of chlorine with methane. Three steps in the mechanism for the bromination of propane to form 1-bromopropane are shown below.



- (i) Name the type of mechanism in this reaction.

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(1)

- (ii) Give an essential condition for Step 1 to occur.

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(1)

- (iii) Name the type of step illustrated by Steps 2 and 3.

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(1)



- (iv) In this mechanism, a different type of step occurs in which free radicals combine.  
Name this type of step.  
Write an equation to show how hexane could be formed from two free radicals in the mechanism of this reaction.

Type of step \_\_\_\_\_

Equation \_\_\_\_\_

(2)

- (v) Write an overall equation for the reaction between bromine and propane by the same mechanism to produce octabromopropane ( $C_3Br_8$ ).

\_\_\_\_\_

(1)

- (b) Bromine reacts with alkenes, even though bromine is a non-polar molecule.

- (i) Explain why bromine molecules react with the double bonds in alkenes.

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

(2)

- (ii) Name the type of mechanism involved in this reaction.

\_\_\_\_\_

(1)

- (iii) Draw the structure of the compound with  $M_r = 387.6$  formed when penta-1,4-diene ( $H_2C=CHCH_2CH=CH_2$ ) reacts with an excess of bromine.

(1)



- (c) Two products are formed when propene reacts with hydrogen bromide. Draw the structure of the intermediate that leads to the formation of the major product in the reaction of propene with hydrogen bromide. Give the name of this type of intermediate.

Structure of intermediate

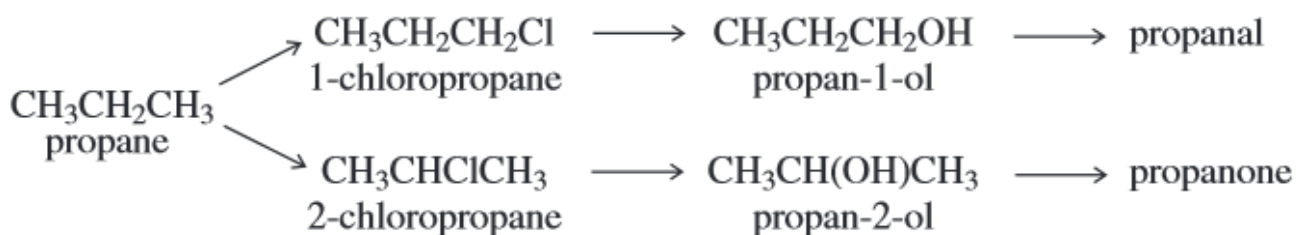
Type of intermediate \_\_\_\_\_

(2)

(Total 12 marks)

### Q28.

Consider the following scheme of reactions.



- (a) State the type of structural isomerism shown by propanal and propanone.

\_\_\_\_\_

(1)

- (b) A chemical test can be used to distinguish between separate samples of propanal and propanone.

Identify a suitable reagent for the test.

State what you would observe with propanal and with propanone.

Test reagent \_\_\_\_\_

Observation with propanal \_\_\_\_\_

Observation with propanone \_\_\_\_\_

(3)



- (c) State the structural feature of propanal and propanone which can be identified from their infrared spectra by absorptions at approximately  $1720\text{ cm}^{-1}$ .

\_\_\_\_\_

(1)

- (d) The reaction of chlorine with propane is similar to the reaction of chlorine with methane.

- (i) Name the type of mechanism in the reaction of chlorine with methane.

\_\_\_\_\_

(1)

- (ii) Write an equation for each of the following steps in the mechanism for the reaction of chlorine with propane to form 1-chloropropane ( $\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$ ).

Initiation step

\_\_\_\_\_

First propagation step

\_\_\_\_\_

Second propagation step

\_\_\_\_\_

A termination step to form a molecule with the empirical formula  $\text{C}_3\text{H}_7$

\_\_\_\_\_

(4)

- (e) High resolution mass spectrometry of a sample of propane indicated that it was contaminated with traces of carbon dioxide.

Use the data in the table to show how precise  $M_r$  values can be used to prove that the sample contains both of these gases.

Atom	Precise relative atomic mass
$^{12}\text{C}$	12.00000
$^1\text{H}$	1.00794
$^{16}\text{O}$	15.99491

\_\_\_\_\_

\_\_\_\_\_

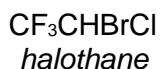
\_\_\_\_\_

(2)

(Total 12 marks)

**Q29.**

One of the first substances used as an anaesthetic in medicine was chloroform (trichloromethane,  $\text{CHCl}_3$ ). By 1950, *halothane* was in common use but by 1990 this had been replaced by more acceptable anaesthetics such as *desflurane*.



One reason for replacing *halothane* was that it is an organic compound that contains chlorine. Chlorine-containing organic compounds are thought to cause damage to the ozone layer in the upper atmosphere.

- (a) Name and outline a mechanism for the reaction of chlorine with methane to form chloromethane ( $\text{CH}_3\text{Cl}$ ).

Write an overall equation for the reaction of chlorine with methane to form trichloromethane ( $\text{CHCl}_3$ ).

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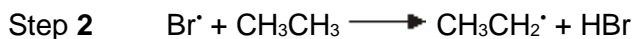
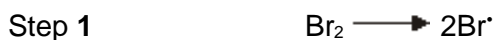
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(5)



**Q30.**

The reaction of bromine with ethane is similar to that of chlorine with ethane. Three steps in the bromination of ethane are shown below.



- (a) (i) Name this type of mechanism.

\_\_\_\_\_

- (ii) Suggest an essential condition for this reaction.

\_\_\_\_\_

- (iii) Steps 2 and 3 are of the same type. Name this type of step.

\_\_\_\_\_

- (iv) In this mechanism, another type of step occurs in which free-radicals combine. Name this type of step. Write an equation to illustrate this step.

Type of step \_\_\_\_\_

Equation \_\_\_\_\_

(5)

- (b) Further substitution in the reaction of bromine with ethane produces a mixture of liquid organic compounds.

- (i) Name a technique which could be used to separate the different compounds in this mixture.

\_\_\_\_\_

- (ii) Write an equation for the reaction between bromine and ethane which produces hexabromoethane,  $\text{C}_2\text{Br}_6$ , by this substitution reaction.

\_\_\_\_\_

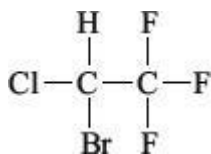
(2)

- (c) The compound 1,2-dibromo-1,1,2,2-tetrafluoroethane is used in some fire extinguishers. Draw the structure of this compound.

(1)



- (d) Halothane is used as an anaesthetic and has the following structure.



- (i) Give the systematic name of *halothane*.

\_\_\_\_\_

- (ii) Calculate the  $M_r$  of halothane.

\_\_\_\_\_

- (iii) Calculate the percentage by mass of fluorine in halothane.

\_\_\_\_\_

(3)

(Total 11 marks)

### Q31.

- (a) Dichloromethane,  $\text{CH}_2\text{Cl}_2$ , is one of the products formed when chloromethane,  $\text{CH}_3\text{Cl}$ , reacts with chlorine.

- (i) Name the type of mechanism involved in this reaction and write an equation for each of the steps named below.

Name of type of mechanism \_\_\_\_\_

Initiation step

\_\_\_\_\_

First propagation step

\_\_\_\_\_

Second propagation step

\_\_\_\_\_

- (ii) Write an overall equation for the formation of dichloromethane from chloromethane.

\_\_\_\_\_

(5)



- (b) A compound contains 10.1% carbon and 89.9% chlorine by mass. Calculate the molecular formula of this compound, given that its relative molecular mass ( $M_r$ ) is 237.0

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(3)

- (c) Suggest the formulae of two bromine-containing organic compounds formed when dibromomethane,  $\text{CH}_2\text{Br}_2$ , reacts with bromine.

Compound 1 \_\_\_\_\_

Compound 2 \_\_\_\_\_

(2)

(Total 10 marks)



## Mark Scheme

### Q26.

- (a) (i) chlorotrifluoromethane  
*Spelling must be correct but do not penalise "flouro"*  
*Ignore use of 1-* 1
- (ii)  $\text{CF}_3\cdot$   
*May be drawn out with dot on C*  
*OR if as shown dot may be anywhere* 1
- (iii) An unpaired/non-bonded/unbonded/free/a single/one/lone electron  
electron  
*NOT "bonded electron" and NOT "paired electron"*  
*NOT "pair of electrons"*  
*NOT "electrons"*  
*Ignore "(free) radical"* 1
- (b) **M1**  $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2$
- M2**  $\text{ClO}\cdot + \text{O}_3 \rightarrow 2\text{O}_2 + \text{Cl}\cdot$   
*Mark independently*  
*Equations could gain credit in either position*  
*The dot can be anywhere on either radical*  
*Penalise the absence of a dot on the first occasion that it is seen and then mark on. Do not make the same penalty in the next equation, but penalise the absence of a dot on the other radical.*  
*Apply the list principle for additional equations* 2
- (c) (i) (If any factor is changed which affects an equilibrium), the (position of) equilibrium will shift/move so as to oppose the change.  
**OR**  
 (When a system/reaction in equilibrium is disturbed), the equilibrium shifts/moves in a direction which tends to reduce the disturbance  
*Must refer to equilibrium*  
*Ignore reference to "system" alone*  
*A variety of wording will be seen here and the key part is the last phrase.*  
*An alternative to shift/move would be the idea of changing/altering the position of equilibrium* 1
- (ii) **M1** The (forward) reaction/to the right is endothermic or



takes in heat

**OR** The reverse reaction/to the left is exothermic or gives out heat

**M2** The equilibrium moves/shifts to oppose the increase in temperature

*M2 depends on a correct statement for M1*

*For M2 accept*

*The equilibrium moves/shifts*

- *to take in heat/lower the temperature*
- *to promote the endothermic reaction and take in heat/ lower the temperature*
- *to oppose the change and take in heat/lower the temperature*  
(leading to the formation of more ozone)

2

(d) Any one of

- Pentane does not contain chlorine OR C-Cl (bond)
- Pentane is chlorine-free
- Pentane does not release chlorine (atoms/radicals)  
*Ignore reference to F OR C-F OR halogen*  
*Ignore "Pentane is not a CFC"*  
*Ignore "Pentane is a hydrocarbon"*  
*Ignore "Pentane only contains C and H"*  
*Ignore "Pentane is C<sub>5</sub>H<sub>12</sub>"*

1

[9]

### Q27.

(a) (i) (Free-) radical substitution  
*Both words needed*

1

(ii) UV light/Ultra-violet light/sunlight  
OR high temperature/ $150\text{ }^{\circ}\text{C} \leq T \leq 500\text{ }^{\circ}\text{C}$

1

(iii) Propagation (Step)  
*Ignore "first" or "second"*  
*Accept phonetic spelling*

1

(iv) **M1** Termination (Step)

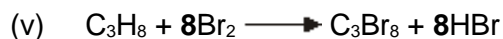
**M2**  $2\text{CH}_3\text{CH}_2\text{CH}_2\cdot \longrightarrow \text{C}_6\text{H}_{14}$   
*In M2*

*C<sub>6</sub>H<sub>14</sub> may be drawn out as CH<sub>3</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>CH<sub>3</sub>*



The dot may be anywhere around the terminal CH<sub>2</sub> on the radical  
 Accept C<sub>3</sub>H<sub>7</sub>• with dot anywhere  
 Penalise the absence of any radical dot

2



Or multiples

1

- (b) (i) **M1** Double bonds are  
 electron-rich

OR electron pair donors

OR centres of electron density.

**M2** Bromine becomes polarised/becomes polar

OR forms an induced dipole

OR becomes δ+/δ-

M1 QoL – require one of these terms

Ignore “(very) negative” and “nucleophile” as applied to the double bond.

Penalise M2 for ion formation from bromine

For M2, do not credit dipole formation solely as a consequence of electronegativity

2

- (ii) Electrophilic addition

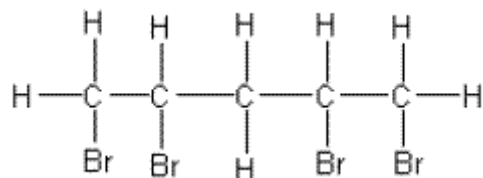
Both words needed

Accept phonetic spelling

1

- (iii) Structure for 1,2,4,5-tetrabromopentane, for example  
 BrCH<sub>2</sub>CHBrCH<sub>2</sub>CHBrCH<sub>2</sub>Br

OR



Must be clear that they have drawn 1,2,4,5-tetrabromopentane  
 and does NOT need to be displayed

Credit use of “sticks” for each C-H bond

1

- (c) +

**M1** Structure of CH<sub>3</sub>CHCH<sub>3</sub>



**M2** (Secondary) Carbocation OR (secondary) carbonium ions

*Mark independently*

*For M1 the positive charge must be on the central carbon atom*

*Penalise bond to positive charge*

*Penalise answers which show more than the correct carbocation e.g. the mechanism, unless the intermediate is clearly identified*

*Credit use of "sticks" for each C-H bond*

*For M2, penalise "primary" or "tertiary"*

2

[12]

**Q28.**

(a) Functional group (isomerism)

1

(b)

**M1** Tollens' (reagent)  
*(Credit ammoniacal silver nitrate  
OR a description of making  
Tollens')*  
*(Ignore either  $\text{AgNO}_3$  or  $[\text{Ag}(\text{NH}_3)_2]^+$   
or "the silver mirror test" on their  
own, but mark M2 and M3)*

**M2** silver mirror

**OR**

black solid/precipitate  
*(NOT silver precipitate)*

**M3** (stays) colourless  
or no change or no reaction

**M1** Fehling's (solution) or  
Benedict's solution  
*(Ignore  $\text{Cu}^{2+}(\text{aq})$  or  
 $\text{CuSO}_4$  on their own, but mark  
on to M2 and M3)*

**M2** Red solid/precipitate  
*(Credit orange or brown solid)*

**M3** (stays) blue  
or no change or no reaction

Mark on from an incomplete/incorrect attempt at the correct reagent, penalising M1

*No reagent, CE=0*

*Allow the following alternatives*

**M1** (acidified) potassium dichromate(VI) (solution)

**M2** (turns) green

**M3** (stays) orange/no change

**OR**

**M1** (acidified) potassium manganate(VII) (solution)

**M2** (turns) colourless

**M3** (stays) purple/no change

*For M3*

*Ignore "nothing (happens)"*

*Ignore "no observation"*

3

(c) (Both have) C=O **OR** a carbonyl (group)

1

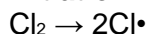
(d) (i) (Free-) radical substitution ONLY



*Penalise "(free) radical mechanism"*

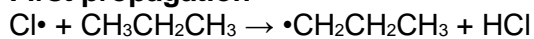
1

(ii) **Initiation**



*Penalise absence of dot once only.*

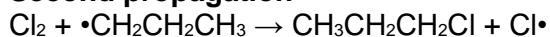
**First propagation**



*Penalise incorrect position of dot on propyl radical once only.*

*Penalise  $\text{C}_3\text{H}_7\cdot$  once only*

**Second propagation**

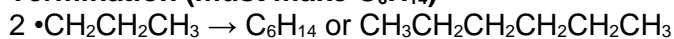


**OR**



*Accept  $\text{CH}_3\text{CH}_2\text{CH}_2\cdot$  with the radical dot above/below/to the side of the last carbon.*

**Termination (must make  $\text{C}_6\text{H}_{14}$ )**



*Use of the secondary free radical might gain 3 of the four marks*

4

- (e)  $M_r = \underline{44.06352}$  (for propane)  
 $M_r = \underline{43.98982}$  (for carbon dioxide)

*Mark independently*

**M1** a correct value for both of these  $M_r$  values.

**M2** a statement or idea that two peaks appear (in the mass spectrum)

**OR**

two molecular ions are seen (in the mass spectrum).

2

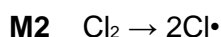
[12]

**Q29.**

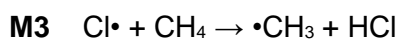
- (a) **M1** (Free-) **radical substitution**

*Both words needed*

1



1



1



1



- M5**  $\text{CH}_4 + 3\text{Cl}_2 \rightarrow \text{CHCl}_3 + 3\text{HCl}$   
 Penalise the absence of a radical dot once only  
**Ignore termination steps except, if and only if both M3 and M4 do not score, then accept for one mark**  
 $\text{Cl}\cdot + \cdot\text{CH}_3 \rightarrow \text{CH}_3\text{Cl}$  1
- (b) **M1** UV (light)/ sunlight / light / UV radiation
- M2** C–Cl or carbon-chlorine bond breakage  
**OR**  
 homolysis of C–Cl  
**OR**  
 equation to show a chlorine-containing organic compound forming two radicals  
 For M1 and M2, ignore use of  $\text{Cl}_2$ , but credit UV and C–Cl bond breakage if seen 1
- M3**  $\text{Cl}\cdot + \text{O}_3 \rightarrow \text{ClO}\cdot + \text{O}_2$  1
- M4**  $\text{ClO}\cdot + \text{O}_3 \rightarrow \text{Cl}\cdot + 2\text{O}_2$   
 Ignore other equations  
 Penalise the absence of a radical dot once only  
 Accept radical dot anywhere on either radical. 1
- M5** Any **one** from
- Combination  $2\text{O}_3 \rightarrow 3\text{O}_2$
  - Stated that  $\text{Cl}\cdot$  / chlorine atom is regenerated / not used up
  - Stated that the  $\text{Cl}\cdot$  / chlorine atom is unaffected by the process. 1
- For M5 accept  $\text{Cl}\cdot$  on both sides of the equation
- M6** Stated that the role of the  $\text{Cl}\cdot$  / chlorine atom is to find an alternative route **OR** lower  $E_a$  / activation energy 1
- (c) **M1** Halothane contains C–Cl / Cl  
**OR**  
 Desflurane does not contain C–Cl bonds / Cl  
**OR**  
 Desflurane contains C–F / F as the only halogen  
 Mark independently.  
 For M1, credit the idea that desflurane contains C–F bonds that are difficult to break OR that halothane contains C–Cl bonds which are easy to break. 1
- M2** Desflurane / molecules that have fluorine as the only halogen, cause no damage / do not deplete / do not react



with the ozone (layer)

**OR**

Halothane / chlorine-containing molecules, damage /  
deplete / react with the ozone (layer)

1

[13]

**Q30.**

- (a) (i) (free-)radical substitution  
(both words required for the mark) 1
- (ii) uv light OR sunlight OR high temperature OR 150 °C to 500 °C 1
- (iii) Propagation  
(ignore "chain", "first", "second" in front of the word propagation) 1
- (iv) Termination 1
- $\bullet\text{CH}_2\text{CH}_3 + \text{Br}\bullet \longrightarrow \text{CH}_3\text{CH}_2\text{Br}$   
OR  $2\bullet\text{CH}_2\text{CH}_3 \longrightarrow \text{C}_4\text{H}_{10}$   
(penalise if radical dot is obviously on  $\text{CH}_3$ , but not otherwise)  
(penalise  $\text{C}_2\text{H}_5\bullet$ )  
(credit  $2\text{Br}\bullet \longrightarrow \text{Br}_2$ )  
(ignore "chain" in front of the word termination) 1
- (b) (i) Fractional distillation OR fractionation  
(credit gas-liquid chromatography, GLC) 1
- (ii)  $\text{CH}_3\text{CH}_3 + 6\text{Br}_2 \longrightarrow \text{C}_2\text{Br}_6 + 6\text{HBr}$   
(credit  $\text{C}_2\text{H}_6$  for ethane) 1
- (c) Correct structure for  $\text{CF}_2\text{BrCF}_2\text{Br}$  drawn out  
(penalise "F" for fluorine) 1
- (d) (i) 2-bromo-2-chloro-1,1,1-trifluoroethane  
OR 1-bromo-1-chloro-2,2,2-trifluoroethane  
(insist on all numbers, but do not penalise failure to use alphabet)  
(accept "flourine" and "cloro" in this instance) 1
- (ii) 197.4 only  
(ignore units)



1

(iii)  $(57/197.4 \times 100) = 28.9\%$  OR  $28.88\%$

*(credit the correct answer independently in part (d)(iii), even if (d)(ii) is blank or incorrectly calculated, but mark consequential on part (d)(ii), if part (d)(ii) is incorrectly calculated, accepting answers to 3sf or 4sf only)*

*(penalise 29% if it appears alone, but not if it follows a correct answer)*

*(do not insist on the % sign being given)*

*(the percentage sign is not essential here, but penalise the use of units e.g. grams)*

1

[11]

**Q31.**

(a) (i) (free-) radical substitution

*(both words required for the mark)*

1

initiation  $\text{Cl}_2 \rightarrow 2\text{Cl}\cdot$

*(credit correct half arrows, but penalise double headed arrows)*

1

first propagation  $\text{CH}_3\text{Cl} + \text{Cl}\cdot \rightarrow \cdot\text{CH}_2\text{Cl} + \text{HCl}$

1

second propagation  $\cdot\text{CH}_2\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{Cl}\cdot$

*(penalise the absence of dots on radicals once only)*

*(penalise radical dot on Cl of  $\text{CH}_2\text{Cl}$  once only)*

1

(ii)  $\text{CH}_3\text{Cl} + \text{Cl}_2 \rightarrow \text{CH}_2\text{Cl}_2 + \text{HCl}$

*(penalise if any radicals appear in this equation)*

1

(b) **M1:** mol C =  $10.1/12.0$  and mol Cl =  $89.9/35.5$

1

**M2:** Ratio  $0.842 : 2.53$  OR  $1 : 3$  OR  $\text{CCl}_3$

1

**M3:**  $237.0/\text{Mr of } \text{CCl}_3 = 237.0/118.5 = 2$  Therefore  $\text{C}_2\text{Cl}_6$

*(correct answer gains full credit)*

1

OR

**M1:**  $237.0 \times 10.1/100$  and  $237 \times 89.9/100$

1

**M2:** Ratio  $23.9/12.0 : 213/35.5$  OR  $2 : 6$

1

**M3:**  $\text{C}_2\text{Cl}_6$

*(correct answer gains full credit)*



1

- (c) any two from  $\text{CHBr}_3$  or  $\text{CBr}_4$  or  $\text{C}_2\text{H}_2\text{Br}_4$  (or  $\text{CHBr}_2\text{CHBr}_2$ ) or  $\text{C}_2\text{Br}_6$  (or  $\text{CBr}_3\text{CBr}_3$ )

*(ignore HBr or  $\text{H}_2$ )*

*(ignore equations and ignore names when given in addition to formulae)*

*(penalise names alone)*

2

**[10]**