Topic 7 Fossil Fuels and Carbon Compounds

Unit 27 Alkanes and alkenes

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Content

- Key terms
- Summary
- Unit Exercise

27.1 Alkanes and alkenes (p.99)

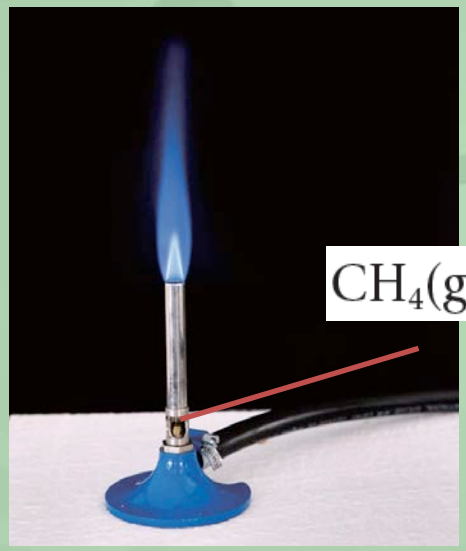
- Alkanes have strong C−C and C−H bonds and are relatively unreactive, except when a strong source of energy is provided.
- They are generally stable under most conditions.
- They do not react with acids, bases, oxidising agents and reducing agents but with oxygen in combustion.

Comparing the properties of alkanes and alkenes *Ref.*

27.1 Alkanes and alkenes (p.99)

Combustion of alkanes

- Complete combustion—with plentiful supply of air or oxygen
- Methane is burnt in a Bunsen burner with a clean, blue non-luminous flame.



$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$$

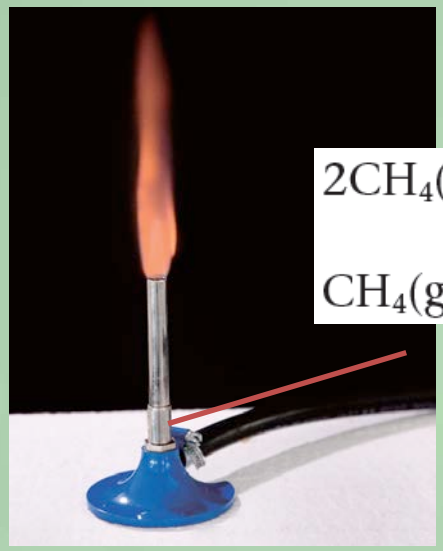
Air hole is fully open.

- Some of the octane in petrol undergoes complete combustion.

$$2C_8H_{18}(g) + 25O_2(g) \longrightarrow 16CO_2(g) + 18H_2O(l)$$

27.1 Alkanes and alkenes (p.99)

- Incomplete combustion—with limited supply of air or oxygen
- This produces carbon soot and makes a cooler, yellow luminous flame.



$$2CH_4(g) + 3O_2(g) \longrightarrow 2CO(g) + 4H_2O(l)$$

$$CH_4(g) + O_2(g) \longrightarrow C(s) + 2H_2O(l)$$

Air hole is closed.

- Different degrees of incomplete combustion of octane:

(Incomplete combustion often happens with hydrocarbons with longer chains as they require more oxygen to burn.)

$$2C_8H_{18}(g) + 17O_2(g) \longrightarrow 16CO(g) + 18H_2O(l)$$

$$2C_8H_{18}(g) + 9O_2(g) \longrightarrow 16C(s) + 18H_2O(l)$$

27.1 Alkanes and alkenes (p.99)

Q (Example 27.1)

One mole of hydrocarbon X requires 9 moles of oxygen for complete combustion. Hydrocarbon X contains 6 carbon atoms per molecule. What is the molecular formula of X?

A

Let C_6H_y be the molecular formula of X.
The chemical equation below represents the complete combustion of X.

$$C_6H_y(g) + \left(6 + \frac{y}{4}\right)O_2(g) \longrightarrow 6CO_2(g) + \frac{y}{2}H_2O(l)$$

$$6 + \frac{y}{4} = 9$$

$$y = 12$$

∴ the molecular formula of X is C_6H_{12}.

27.1 Alkanes and alkenes (p.99)

Reaction with halogens—substitution reactions

- Alkanes react with Cl_2 and Br_2 under heat or UV.

$$CH_4(g) + Cl_2(g) \xrightarrow{\text{sunlight or heat}} \underset{\text{chloromethane}}{CH_3Cl(g)} + HCl(g)$$

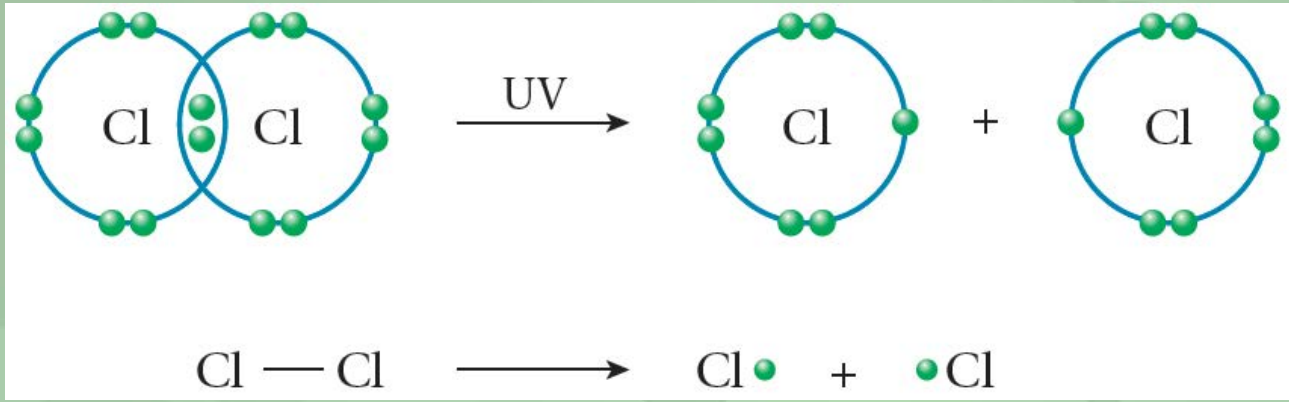
- This is a **substitution reaction (取代反應)**—one in which an atom or group of atoms in a molecule is replaced by another atom or group of atoms.

- The above methane reaction takes place in 3 stages: **initiation (引發)**, **propagation (傳播)** and **termination (終止)**.

27.1 Alkanes and alkenes (p.99)

Initiation

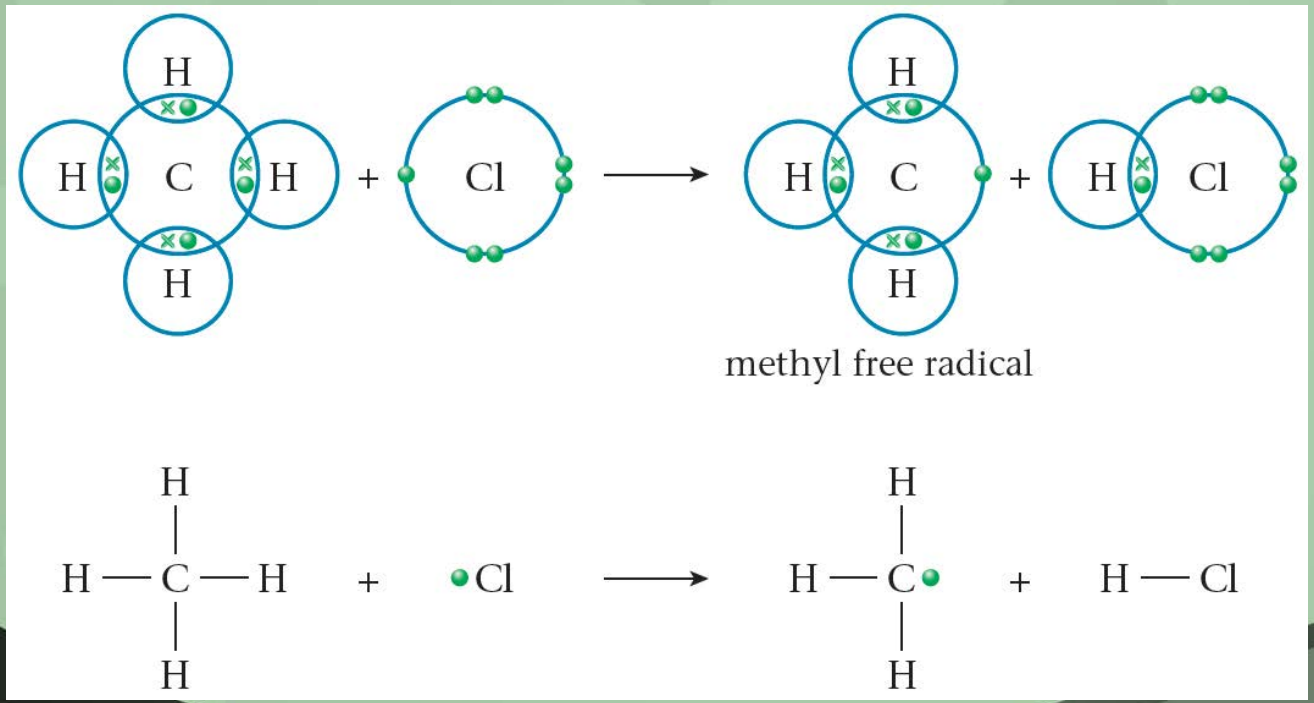
- Forming **free radicals (自由基)** under heat or UV:



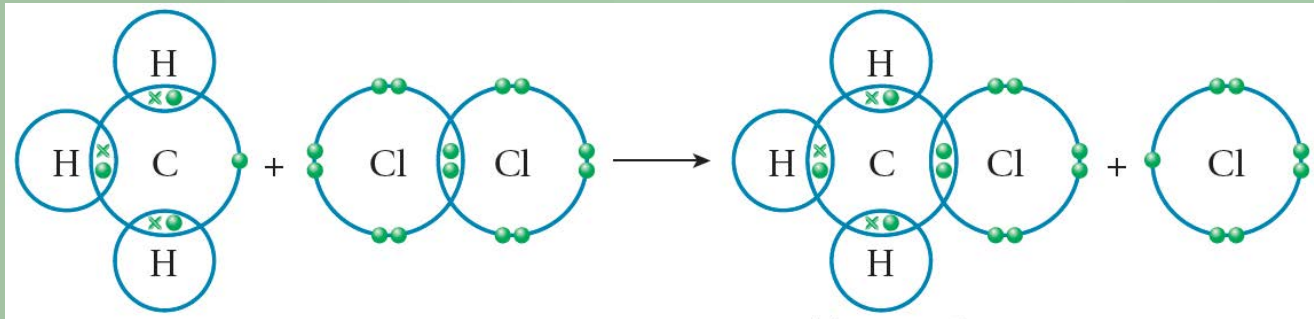
27.1 Alkanes and alkenes (p.99)

Propagation

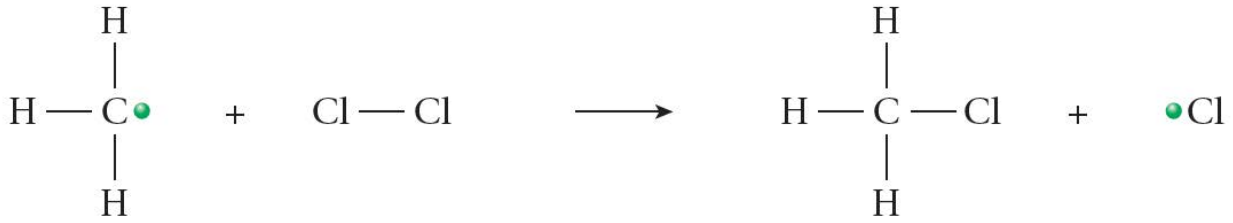
- **Chain reaction (連鎖反應)** takes place. One initial event causes a large number of subsequent reactions, with the reactive chemical species being regenerated in each cycle



27.1 Alkanes and alkenes (p.99)



chloromethane

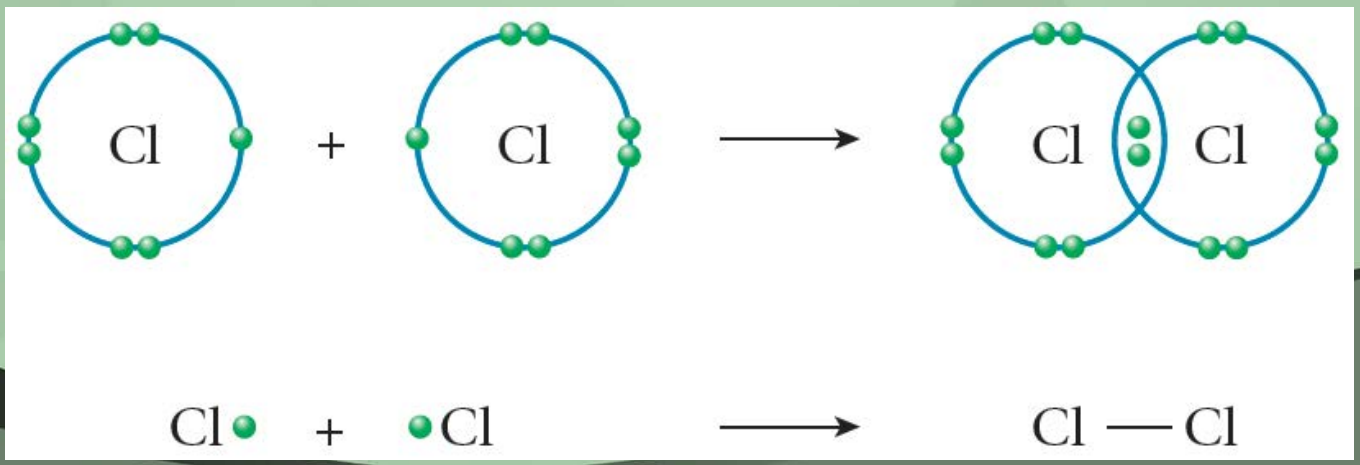


27.1 Alkanes and alkenes (p.99)

Termination

- The chance of two free radicals (present in very low concentrations) colliding is very low.
- Once they collide, the chain reaction will be brought to an end.
- Before a termination step stops the reaction, up to a million propagation cycles have already taken place.
- Possible termination steps:

(1)



27.1 Alkanes and alkenes (p.99)

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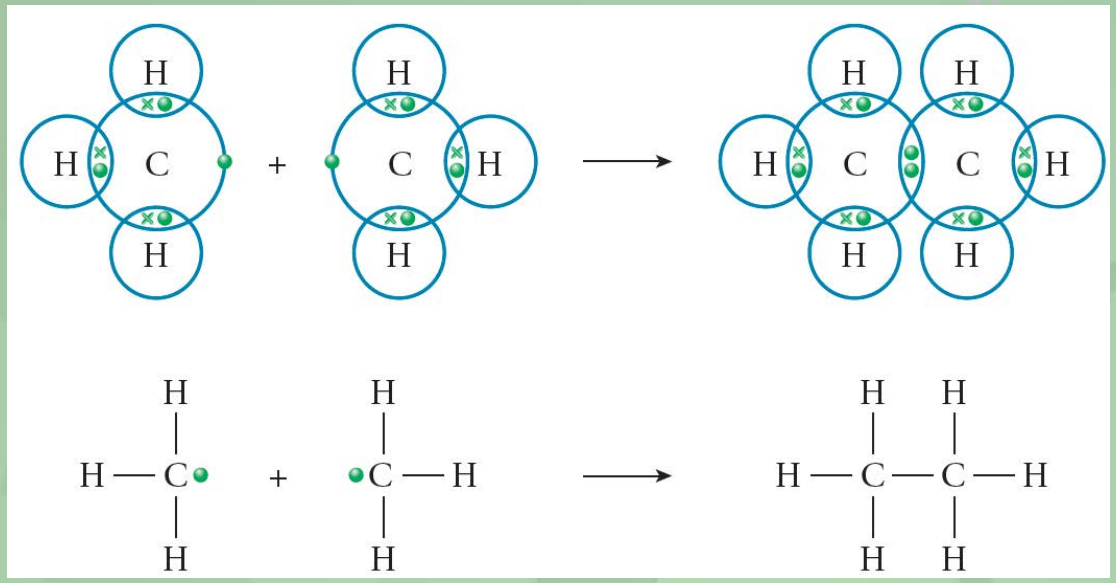

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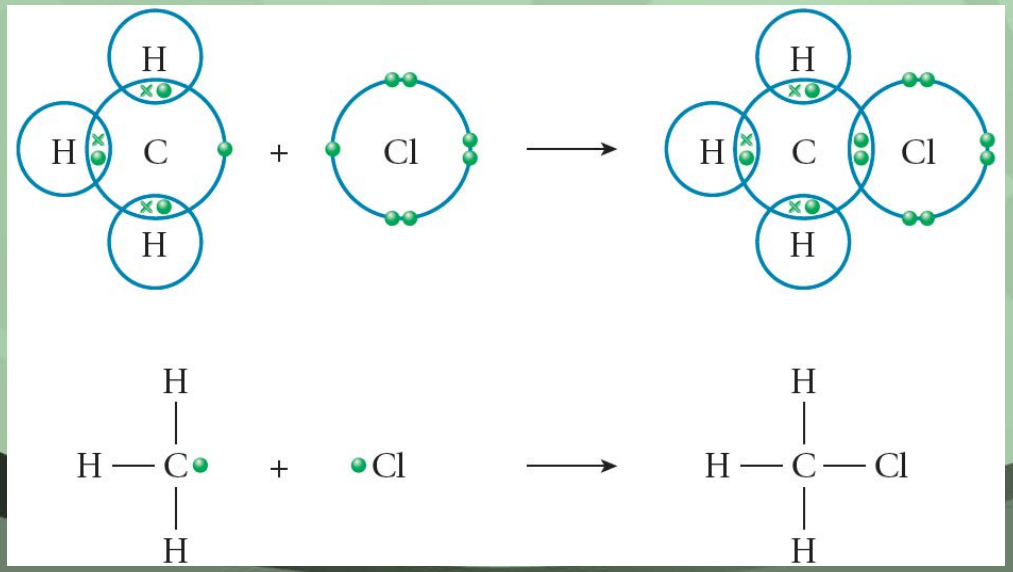


27.1 Alkanes and alkenes (p.99)

Further substitution reactions

- The product chloromethane (CH_3Cl) still contains 3 hydrogen atoms, which can further by replaced, one by one, by a chlorine atom in similar substitution reactions.
- A mixture of *di-*, *tri-* and *tetra*-substituted products results.

Formation of dichloromethane:

$$CH_3Cl(g) + Cl_2(g) \longrightarrow CH_2Cl_2(l) + HCl(g)$$

Formation of trichloromethane:

$$CH_2Cl_2(l) + Cl_2(g) \longrightarrow CHCl_3(l) + HCl(g)$$

Formation of tetrachloromethane:

$$CHCl_3(l) + Cl_2(g) \longrightarrow CCl_4(l) + HCl(g)$$

27.1 Alkanes and alkenes (p.99)

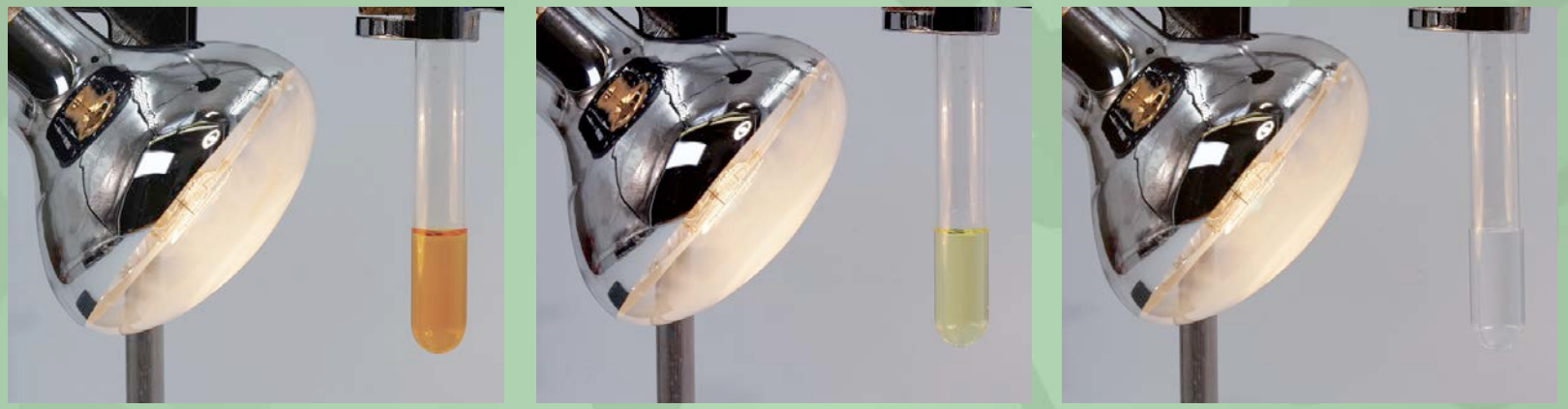
- The different boiling points of the four chloromethanes allow the mixture of products to be separated by fractional distillation.

Compound	Molecular formula	Boiling point (°C)
Chloromethane	CH_3Cl	–24
Dichloromethane	CH_2Cl_2	40
Trichloromethane	$CHCl_3$	62
Tetrachloromethane	CCl_4	77

- Using excess methane reduces the likelihood of further substitution but cannot prevent getting a mixture of products.
- Thus, radical substitution is not an effective method for the preparation of chloromethane.

27.1 Alkanes and alkenes (p.99)

- The reaction of alkanes with bromine is much slower.



The effect of light on a mixture of bromine and hexane after 0, 10 and 16 seconds

27.1 Alkanes and alkenes (p.99)

Practice 27.1

1 Explain why a non-luminous flame is obtained when the air hole of a Bunsen burner is fully open. Enough oxygen is provided. The fuel undergoes complete combustion.

2 The alkanes are a family of saturated hydrocarbons. The largest use for alkanes is as fuels.

a) What is the general formula for alkanes? C_nH_{2n+2}

b) The complete combustion of alkanes produces carbon dioxide and water only. Write the chemical equation for the complete combustion of nonane, C_9H_{20}. $C_9H_{20}(g / l) + 14O_2(g) \rightarrow 9CO_2(g) + 10H_2O(l)$

c) An incomplete combustion of nonane, C_9H_{20}, results in the formation of carbon monoxide and water only.

$2C_9H_{20}(g / l) + 19O_2(g) \rightarrow 18CO(g) + 20H_2O(l)$

27.1 Alkanes and alkenes (p.99)

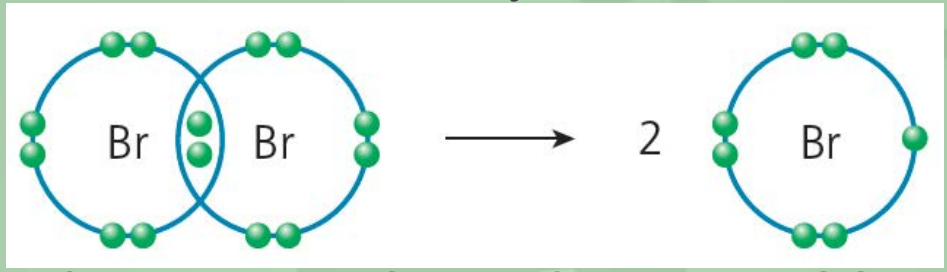
d) State TWO problems that result from the incomplete combustion of alkane fuels.

Any two of the following:

- Carbon monoxide is toxic.
- Less energy is produced, becomes a less efficient fuel.
- Unburnt hydrocarbons react to form toxic / harmful compounds.
- Sooty deposits / carbon / particulates in atmosphere.

27.1 Alkanes and alkenes (p.99)

3 Bromine reacts with methane to form bromomethane (CH_3Br) via a free radical chain reaction.
The initiation step is shown below. Only electrons in the *outermost shells* are shown.



a) Name the type of the reaction for the formation of CH_3Br from methane and bromine. Substitution reaction

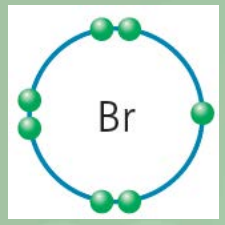
b) State the condition needed for the reaction to occur. Ultraviolet light / heat / radical initiator

c) State the expected observation for the reaction.

Any one of the following:
- The orange / brown colour fades.
- The orange / brown colour changes to colourless slowly.

27.1 Alkanes and alkenes (p.99)

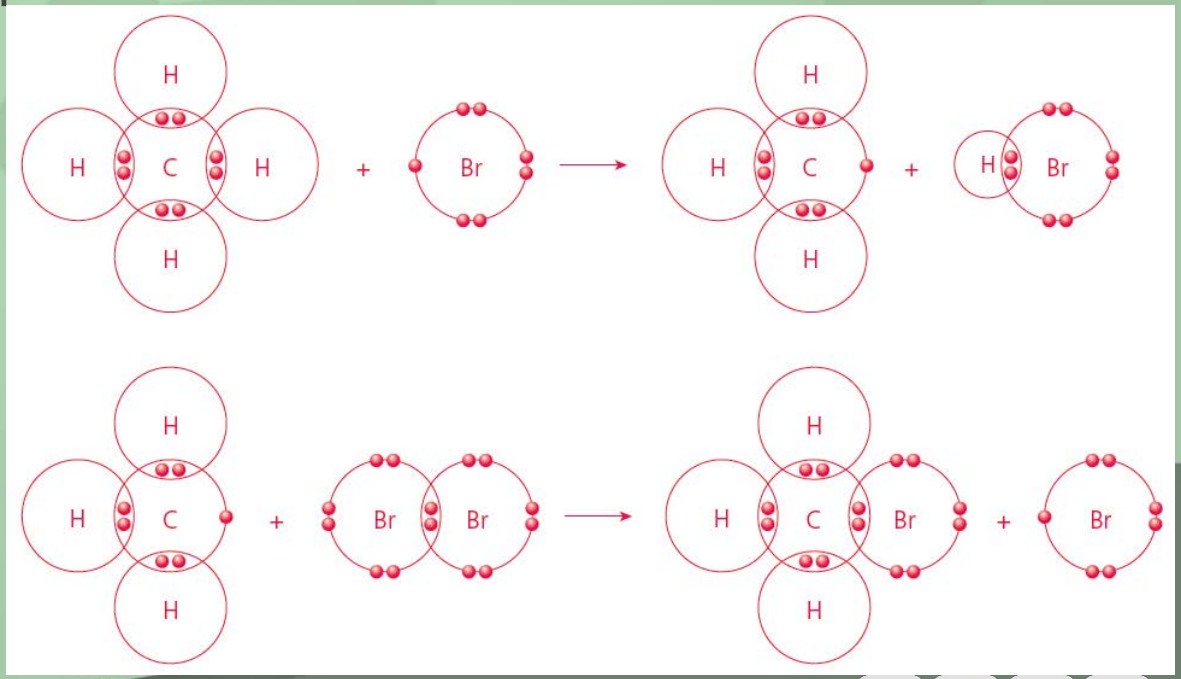
d) With reference to its electronic structure, explain why the chemical species



has a high reactivity.

Any one of the following:
- The Br atom does not have a stable noble gas electronic arrangement.
- The Br atom does not have a stable octet electronic arrangement.

e) Give TWO propagation steps of the reaction between methane and bromine to form CH_3Br.



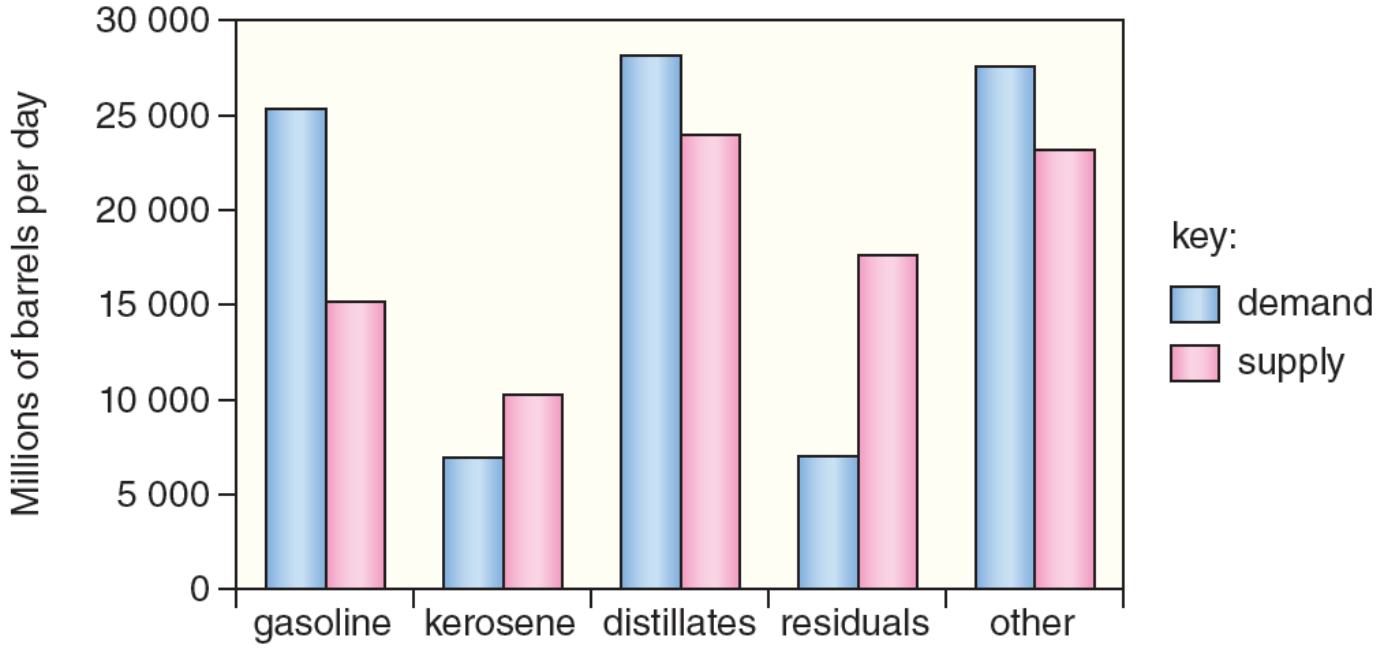
27.1 Alkanes and alkenes (p.99)

f) Suggest why this reaction is NOT an effective way for the preparation of CH_3Br.

The reaction gives a mixture of products (CH_2Br_2, $CHBr_3$, etc.)

27.2 Demand and supply of petroleum fractions (p.108)

- World supply and demand of petroleum fractions:



Gasoline: a mixture of relative volatile hydrocarbons, suitable for use in internal combustion engines

Kerosene: medium distillates in the 150–280 °C distillation range, a fuel for jets and aircrafts

Distillates: middle distillates of hydrocarbons similar to diesel

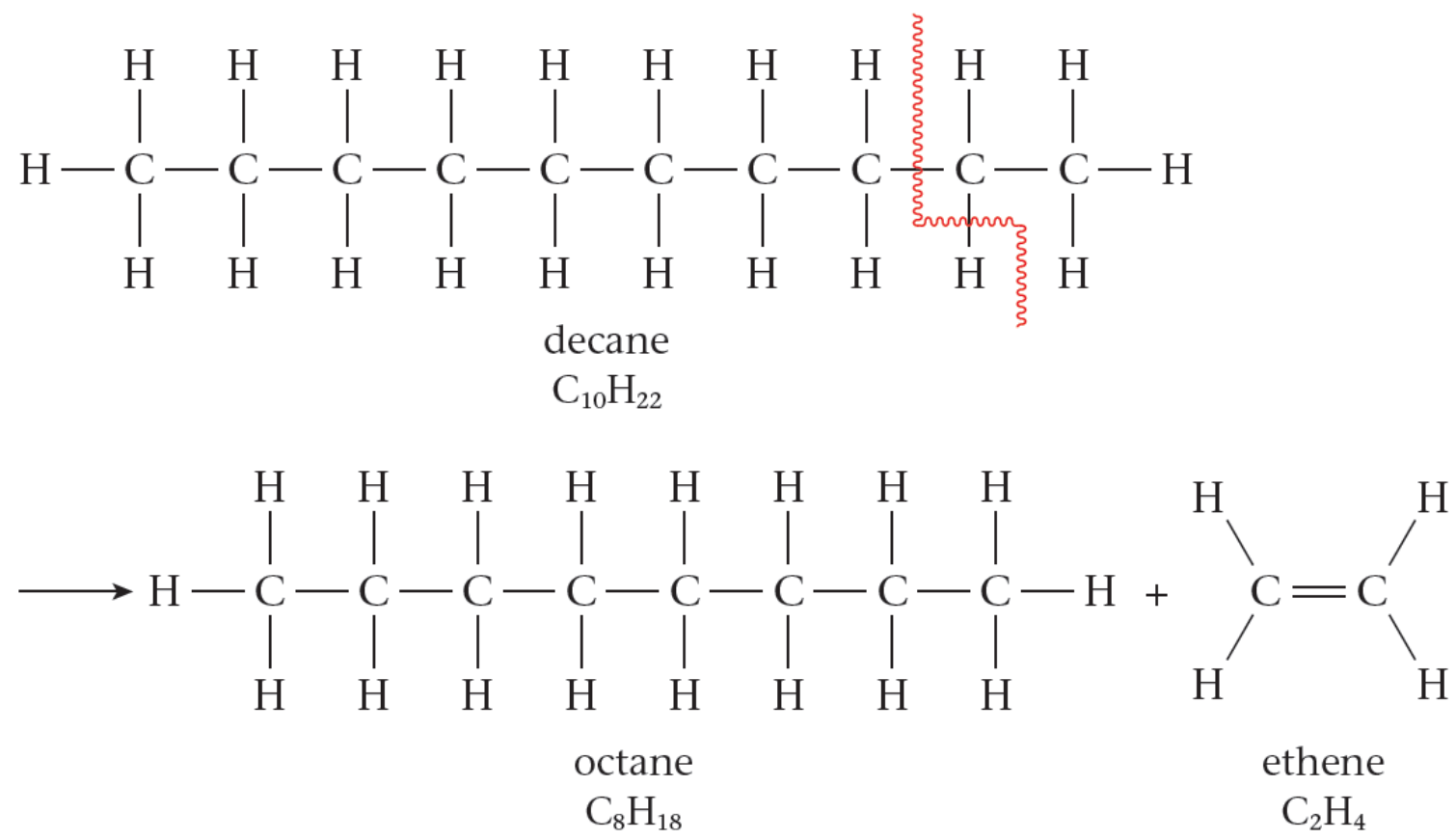
Residuals: fuels obtained as liquid still bottoms from the distillation of crude oil

27.2 Demand and supply of petroleum fractions (p.108)

- To match the supply of useful fractions, large hydrocarbon molecules are broken down with heat or in the presence of catalyst to produce smaller hydrocarbon molecules. This is called cracking.
- In modern **catalytic cracking (催化裂解)**, cracking takes place in a vertical tower about 60 m high and 2 m in diameter.
- Hot vaporized hydrocarbons and catalyst are fed into the bottom of the tower and forced upwards.
- One large molecule is at least broken down into two small molecules.

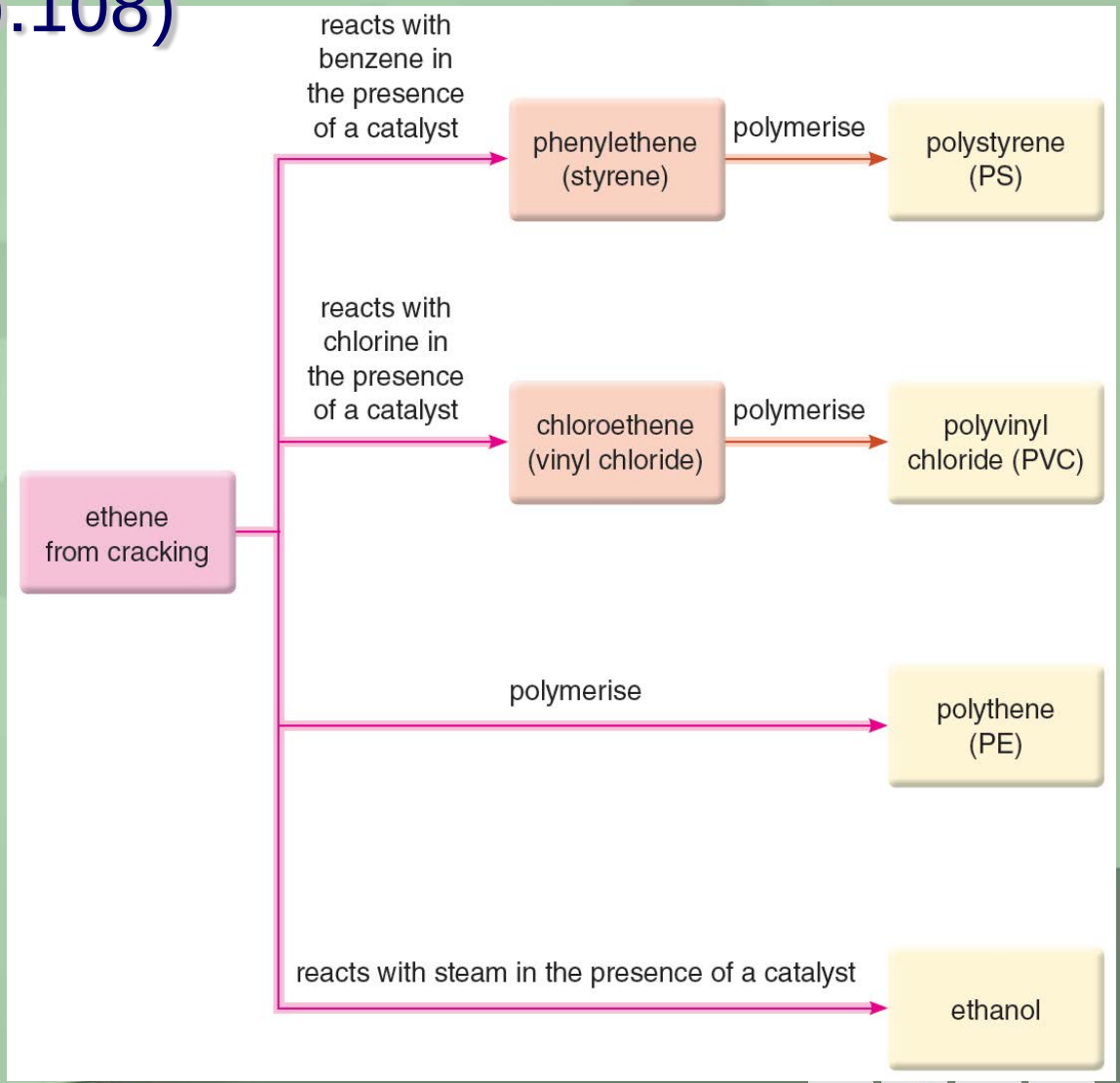
27.2 Demand and supply of petroleum fractions (p.108)

- Decane ($C_{10}H_{22}$) is heated in the presence of a catalyst.
- It may break down into octane and ethene.



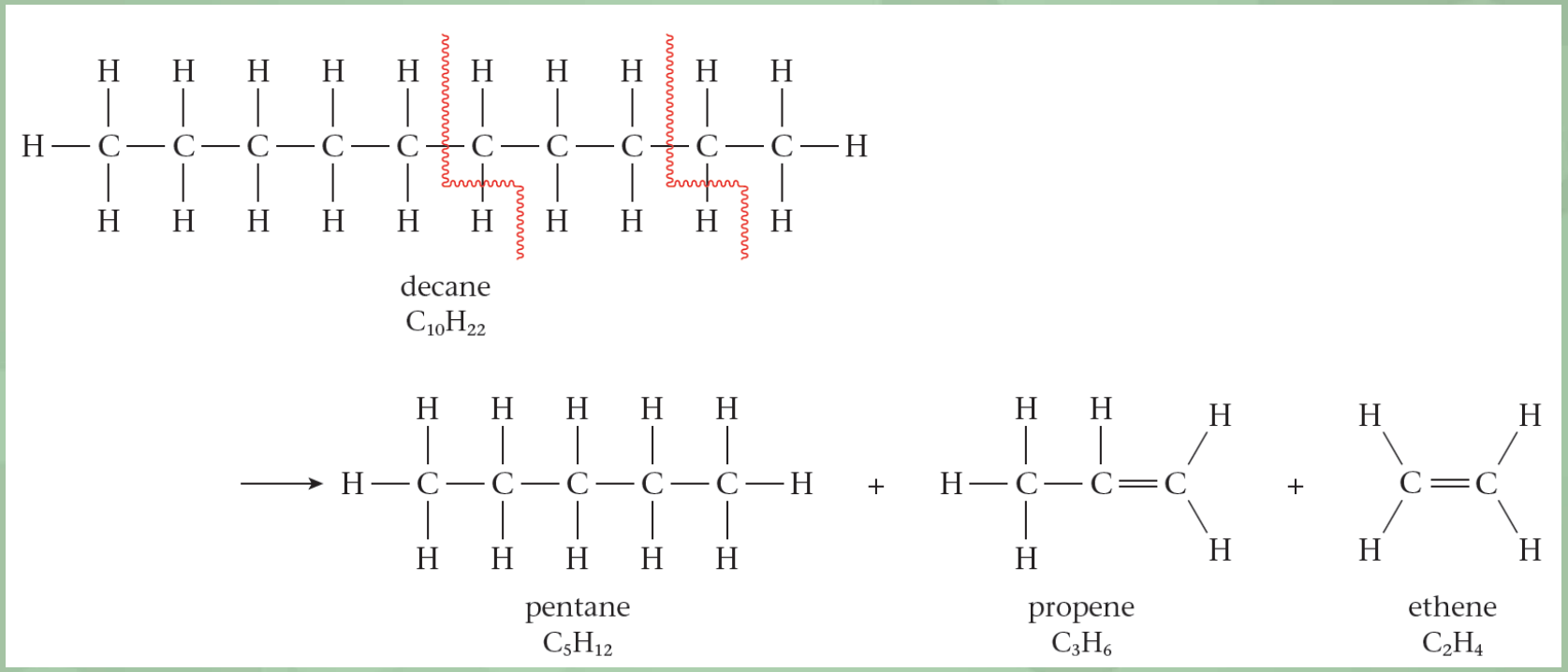
27.2 Demand and supply of petroleum fractions (p.108)

- Octane is added to petrol so as to increase its supply.
- Ethene is an important **feedstock (供料)** for making a wide range of products such as ethanol and synthetic polymers.



27.2 Demand and supply of petroleum fractions (p.108)

- Decane may be split apart in many other ways. For example,



- The products need to be separated by fractional distillation.

27.2 Demand and supply of petroleum fractions (p.108)

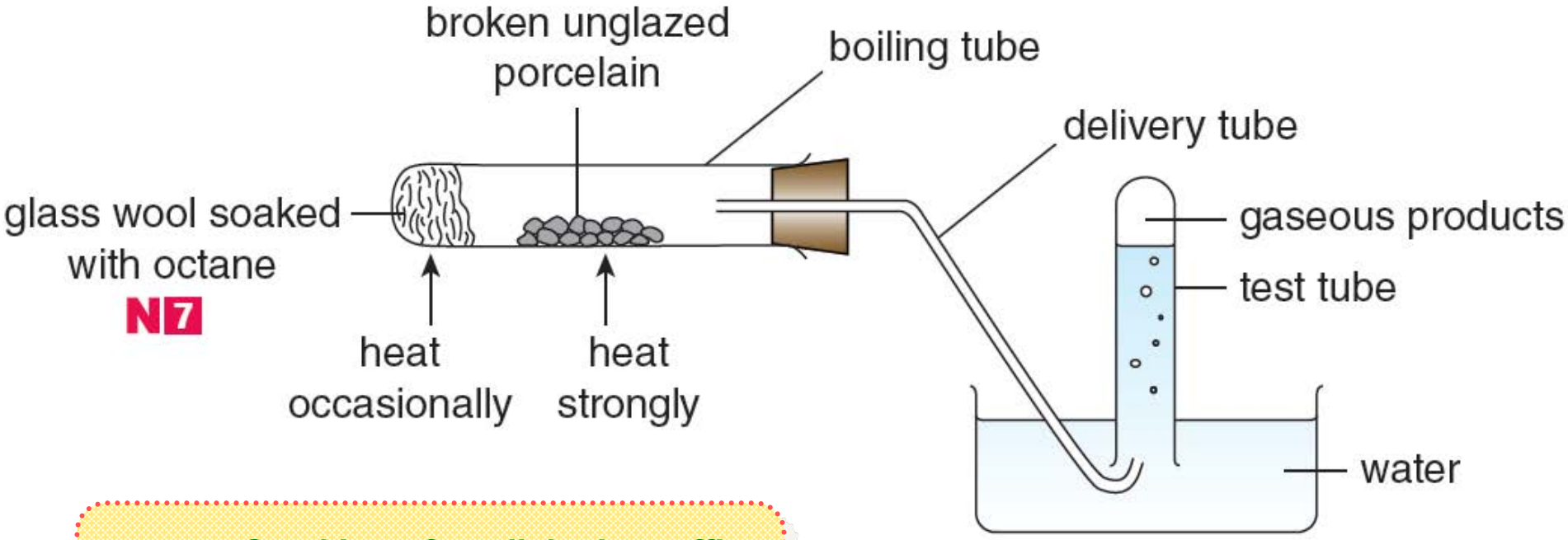
Why is cracking important?

- Make the best use of petroleum.
  e.g. crack fuel oil (too much) to get petrol (in need)
- Cracking always produces small alkene molecules, which are used as feedstocks for a huge range of compounds (e.g. synthetic polymers) and products (e.g. paints, drugs)

27.2 Demand and supply of petroleum fractions (p.108)

Cracking octane in a laboratory

- Cracking can be done in a laboratory using **unglazed porcelain (素瓷)**.



Cracking of medicinal paraffin and testing the gaseous product *Ref.*

27.2 Demand and supply of petroleum fractions (p.108)

- The products are mostly gases (i.e. hydrocarbons with less than 5 carbon atoms per molecule)
- When no more gas can be collected. Remove the delivery tube before removing the heat to avoid sucking back (which can cause the hot boiling tube to break due to sudden cooling).
- Broken (instead of large piece of) unglazed porcelain is used to provide a larger surface area and the reaction will be faster.

27.2 Demand and supply of petroleum fractions (p.108)

Table 27.2 Comparison of some properties of octane and the cracked products

	Octane	Products
Appearance	thick colourless liquid	colourless gas
Smell	no smell	pungent smell
Flammability	difficult to burn	burn readily
Reactivity	unreactive	reactive

- Octane has a high b.p. and is difficult to burn.
  So it has large molecules with long chains of carbon atoms.
- The products have a low b.p. and are gases.
  So they must have small molecules with short carbon chains.

27.2 Demand and supply of petroleum fractions (p.108)

Practice 27.2

Petroleum is processed to give a wide variety of alkanes.

a) i) Give the name of ONE physical process carried out during the processing of petroleum. Fractional distillation

ii) On what properties of alkanes does this physical process depend?

Different boiling points

b) An alkane with molecular formula $C_{25}H_{52}$ found in fuel oil can be split into smaller molecules.

i) Name the important industrial process involved. Cracking

ii) Explain why this process is important.

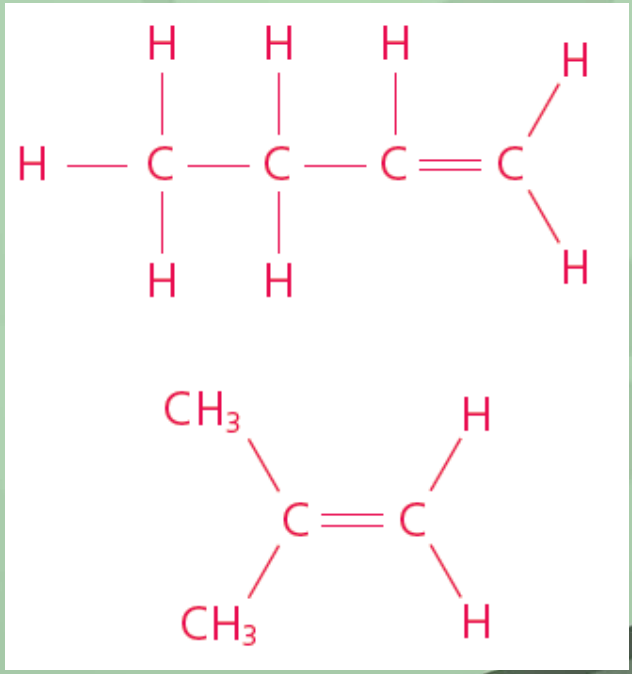
- To produce alkenes which can make a huge range of other compounds.
- To produce smaller hydrocarbons from larger hydrocarbons. / To convert heavy oil to petrol.

27.2 Demand and supply of petroleum fractions (p.108)

iii) The following equation shows one possible reaction that occurs in the process: $C_{25}H_{52} \rightarrow C_{17}H_{36} + 2X$

Give ONE possible structural formula of X.

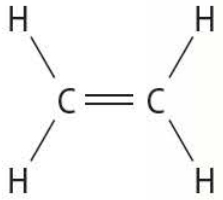
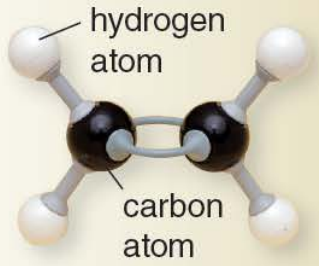
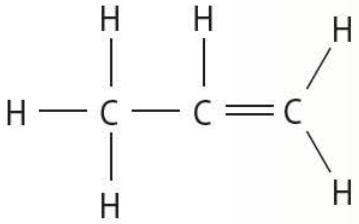
Any one of the following:



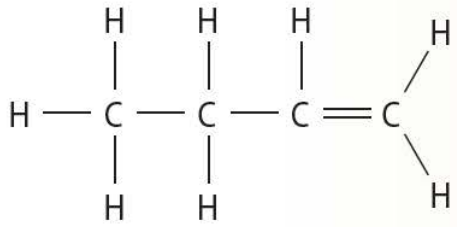
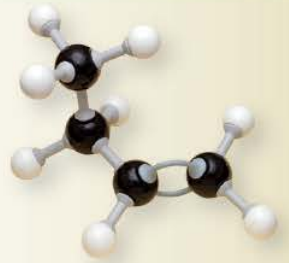
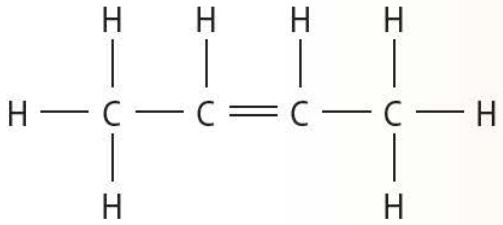
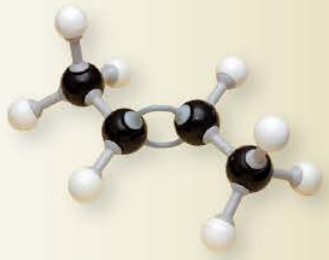
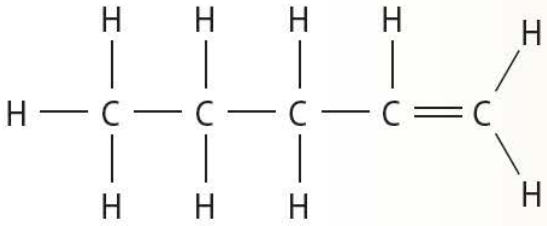
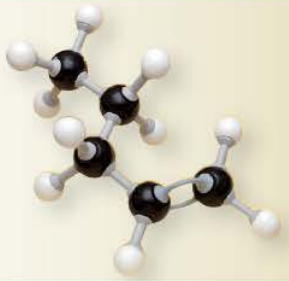
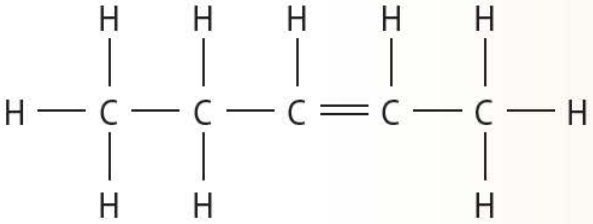
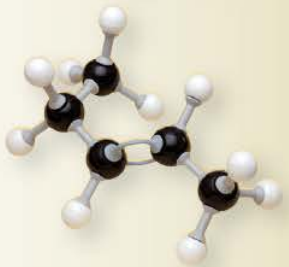
27.3 Alkenes (p.113)

- Alkenes (−C=C−, C_nH_{2n}) are unsaturated hydrocarbons.
- The three electron groups on each carbon repel to give a trigonal planar arrangement.

Table 27.3 Molecular formulae, structural formulae and molecular models of some alkenes

Name	Molecular formula	Structural formula	Molecular model
Ethene	C_2H_4		
Propene	C_3H_6		

27.3 Alkenes (p.113)

But-1-ene	C_4H_8		
But-2-ene	C_4H_8		
Pent-1-ene	C_5H_{10}		
Pent-2-ene	C_5H_{10}		

27.4 Physical properties of alkenes (p.115)

Melting and boiling points

- Increase with increasing carbon chain length
- Very close to corresponding alkanes(only van der Waals' forces)

Table 27.4 Melting points and boiling points of alkenes and alkanes

Alkene	Melting point (°C)	Boiling point (°C)	Alkane	Melting point (°C)	Boiling point (°C)
Ethene	−169	−104	ethane	−183	−89
Propene	−185	−47	propane	−190	−42
But-1-ene	−185	−6	butane	−138	−0.5
Pent-1-ene	−165	30	pentane	−130	36

- At r.t., ethene, propene and but-1-ene are gases while other alkenes are liquids or waxy solids.

Solubility

- Insoluble in water, like alkanes

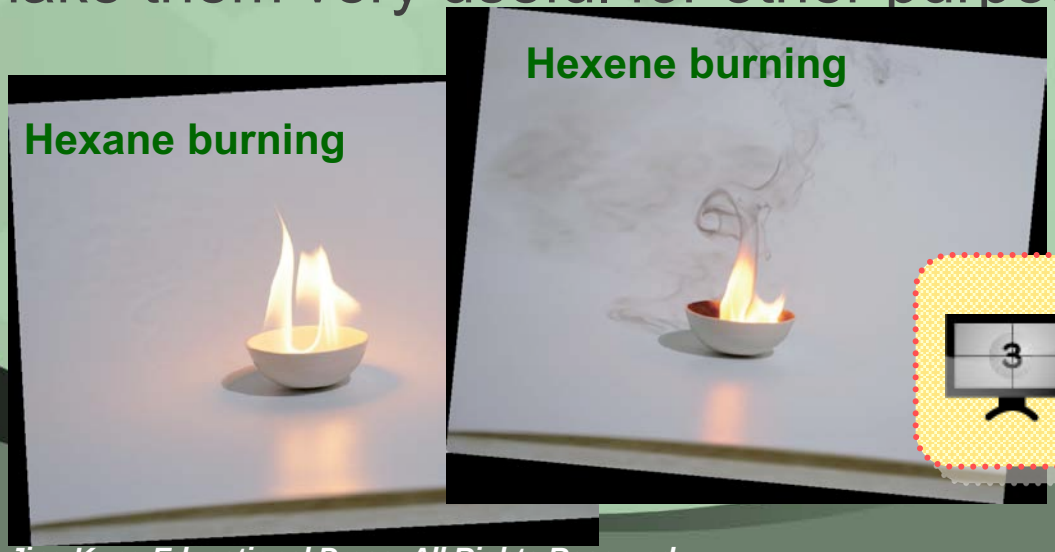
27.5 Important reactions of alkenes (p.115)

Combustion

- An alkene burns with sootier flame than an alkane does.

$$C_2H_4(g) + 3O_2(g) \longrightarrow 2CO_2(g) + 2H_2O(l)$$

- Alkene molecules have a higher carbon to hydrogen ratio.
- Their chance to undergo incomplete combustion to give carbon (soot) is higher.
- Alkenes are rarely burnt as fuels because their reactivities make them very useful for other purposes.

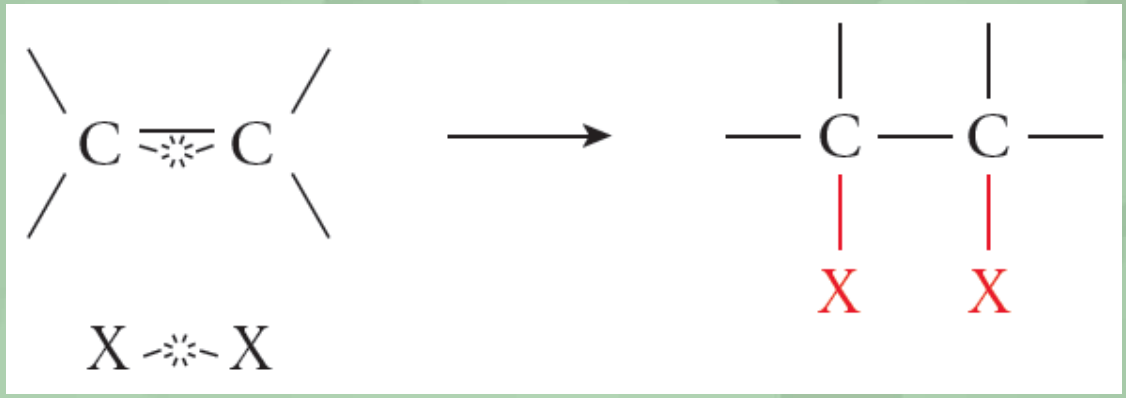


Distinguishing between an alkane and an alkene *Ref.*

27.5 Important reactions of alkenes (p.115)

Addition reactions

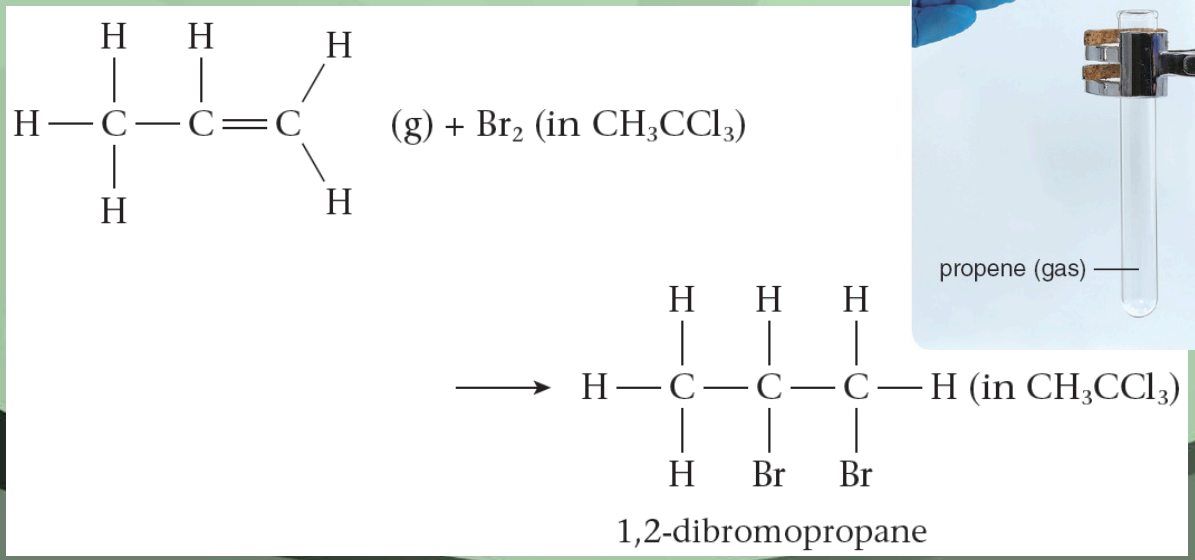
- **Addition reaction (加成反應)**—one in which two or more molecules react to form a single, larger molecule.

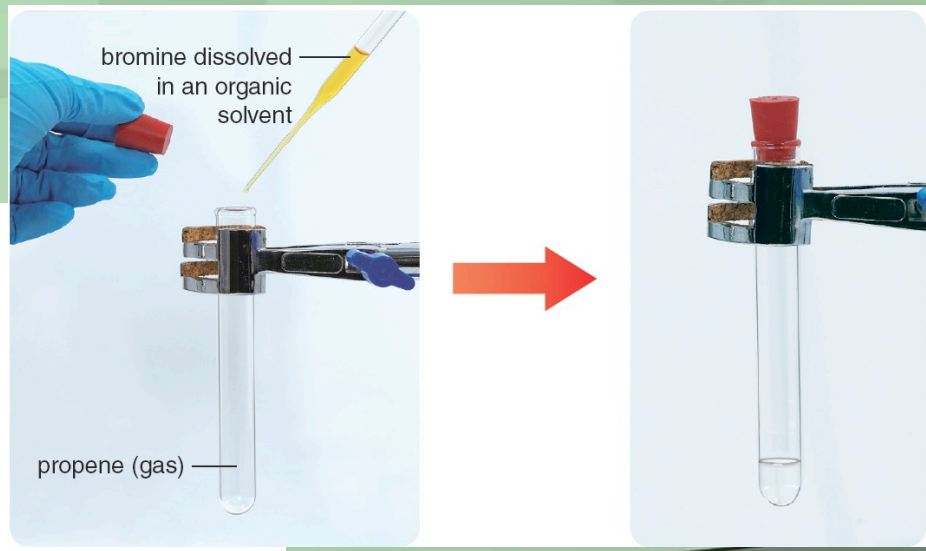


27.5 Important reactions of alkenes (p.115)

Reaction with bromine

- The orange colour of the dissolved bromine (in an organic solvent) disappears quickly because the product is colourless.
- Vigour decreases down the halogen group.
  (F_2 reacts explosively.
  I_2 is slow.)

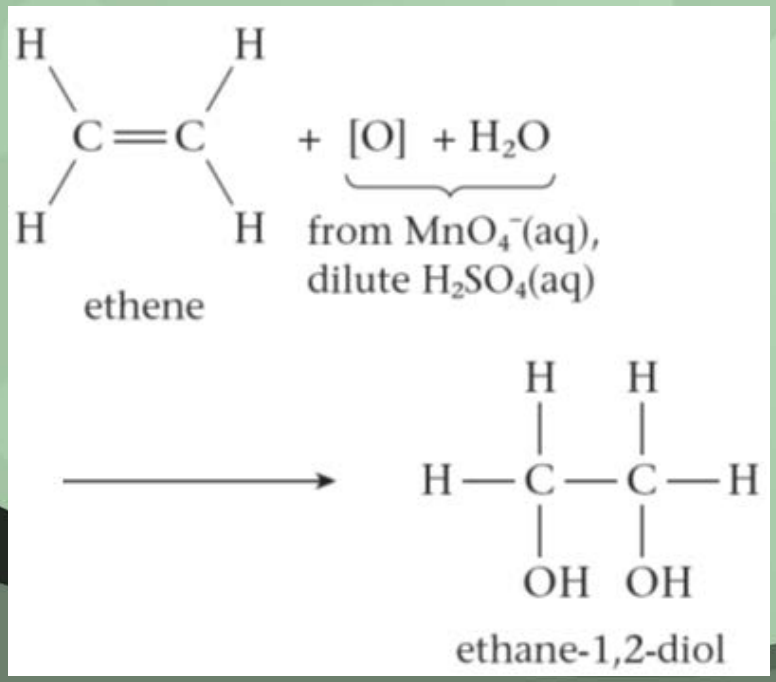


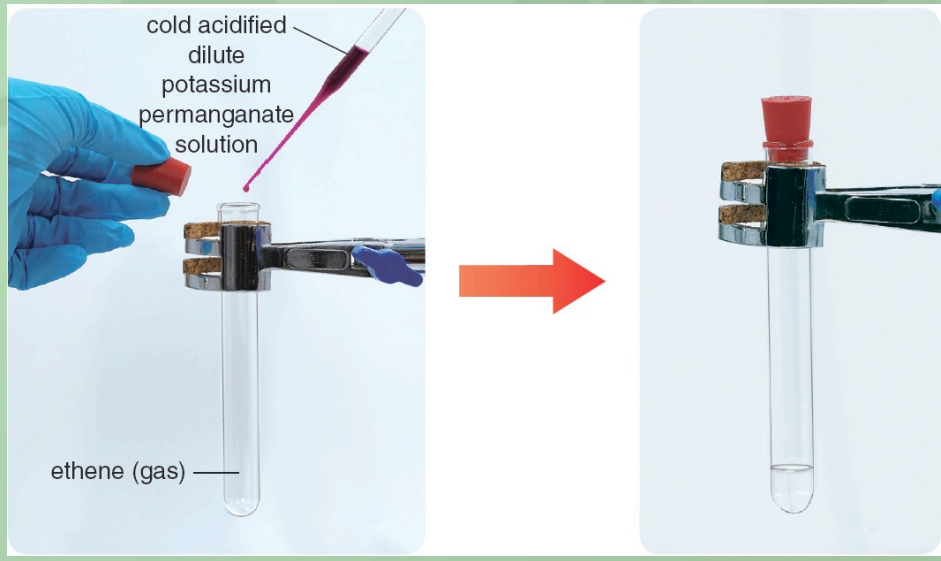


27.5 Important reactions of alkenes (p.115)

Reaction with cold acidified dilute $KMnO_4(aq)$

- Converts an alkene to a diol via an addition reaction.
- The purple solution becomes colourless quickly: $MnO_4^-(aq)$ reduced to very pale pink $Mn^{2+}(aq)$





27.5 Important reactions of alkenes (p.115)

Test for unsaturation

- The orange solution of bromine dissolved in 1,1,1-trichloroethane becomes colourless quickly when shaken with an alkene.
- The purple solution of cold acidified dilute potassium permanganate solution becomes colourless quickly when shaken with an alkene.
- The tests can be used to distinguish alkenes from alkanes, and apply to other unsaturated hydrocarbons, e.g. ethyne HC≡CH.

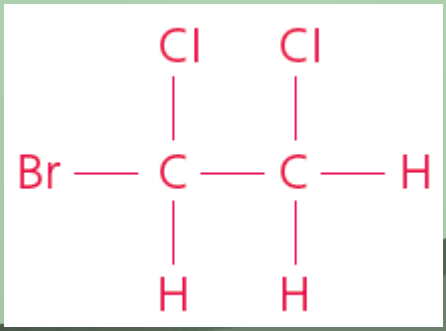
27.5 Important reactions of alkenes (p.115)

Practice 27.3

1 Olympic torches have used a variety of fuels since the first olympic games in 776 B.C. Both propane (C_3H_8) and kerosene are possible choices. Kerosene gives the torch a more visible yellow flame compared to propane. Explain why.

The hydrocarbon molecules in kerosene have a higher carbon to hydrogen ratio than a propane molecule.
Kerosene has a greater chance to undergo incomplete combustion to give carbon (soot).

2 Bromoethene undergoes an addition reaction with chlorine in a suitable organic solvent.
Write the structural formula of the organic product.



27.5 Important reactions of alkenes (p.115)

3 Alkane X can be cracked into octane (C8H18) and but-1-ene such that the mole ratio of octane and but-1-ene is 1 : 1.

a) What is the molecular formula of alkane X? $C_{12}H_{26}$

b) Octane is a component of petrol. Write the chemical equation for the complete combustion of octane.

$2C_8H_{18}(g / l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$

c) Suggest a chemical test to distinguish but-1-ene from octane. State also the expected observations. Any one of the following:

- Add an orange solution of bromine dissolved in 1,1,1-trichloroethane separately to but-1-ene and octane.
  The orange solution of bromine becomes colourless quickly when added to but-1-ene.
  The orange solution of bromine becomes colourless slowly when added to octane under sunlight.
- Add a purple solution of cold acidified dilute potassium permanganate solution to but-1-ene and octane separately.
  The purple solution of potassium permanganate becomes colourless quickly when added to but-1- ene.
  Octane gives no observable change.

27.6 Renewable energy sources in Hong Kong (p.120)

- Fossil fuels are non-renewable energy sources.
- With reduction of fossil fuel reserves and the impact of burning fossil fuels on the environment, **renewable energy sources (可再生能源)** are becoming more important.
- Renewable energy sources are those that can be produced at a rate faster than the rate at which they are used.

27.6 Renewable energy sources in Hong Kong (p.120)

- Solar and wind energy
  - unlimited supply
  - no emission of greenhouse gases or air pollutants

The Zero Carbon Building in Kowloon Bay generates on-site renewable energy from photovoltaic panels and a tri-generation system using biofuel made of waste cooking oil

Wind power *Ref.*

Key terms (p.122)

substitution reaction	取代反應	cracking	裂解
initiation	引發	catalytic cracking	催化裂解作用
propagation	傳播	feedstock	供料
termination	終止	unglazed porcelain	素瓷
free radical	自由基	addition reaction	加成反應
chain reaction	連鎖反應	renewable energy source	可再生能源

Summary (p.123)

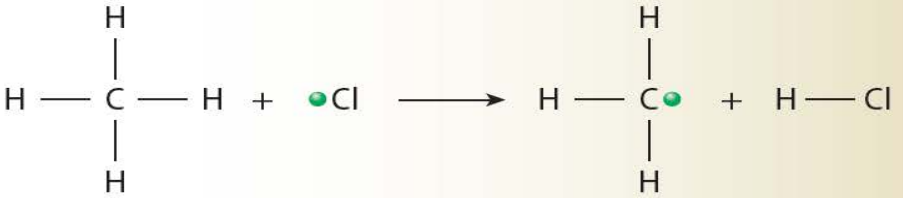
1 The following table summarises two important reactions of alkanes.

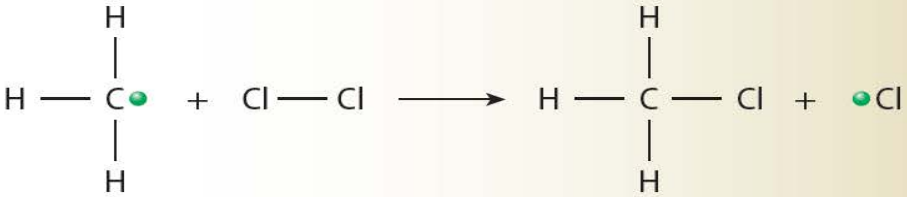
	Reaction	Examples
1	Combustion — when there is a plentiful supply of air or oxygen, an alkane undergoes complete combustion.	$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l)$ $2C_8H_{18}(g) + 25O_2(g) \longrightarrow 16CO_2(g) + 18H_2O(l)$

2 Substitution reactions with halogens — formation of haloalkanes

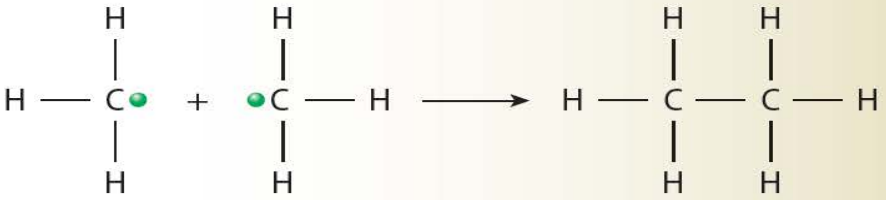
Initiation

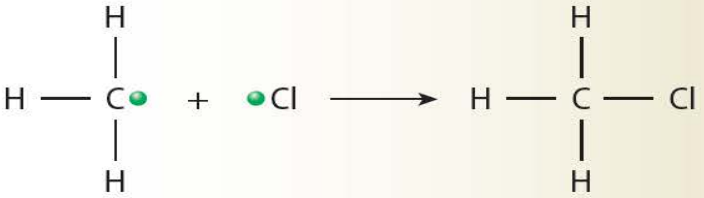
Propagation





Termination





Summary (p.123)

2 The following diagram summarises some important information about cracking.

Cracking	Importance of cracking
The breaking down of large hydrocarbon molecules with heat or in the presence of a catalyst to produce smaller hydrocarbon molecules	• Increasing the amount of petrol available • Producing starting materials to make a range of products such as ethanol and synthetic polymers

Examples of cracking:

$$\underset{\text{decane}}{C_{10}H_{22}(l)} \longrightarrow \underset{\text{octane}}{C_8H_{18}(l)} + \underset{\text{ethene}}{C_2H_4(g)}$$

(a component of petrol)

$$\underset{\text{decane}}{C_{10}H_{22}(l)} \longrightarrow \underset{\text{pentane}}{C_5H_{12}(l)} + \underset{\text{propene}}{C_3H_6(g)} + \underset{\text{ethene}}{C_2H_4(g)}$$

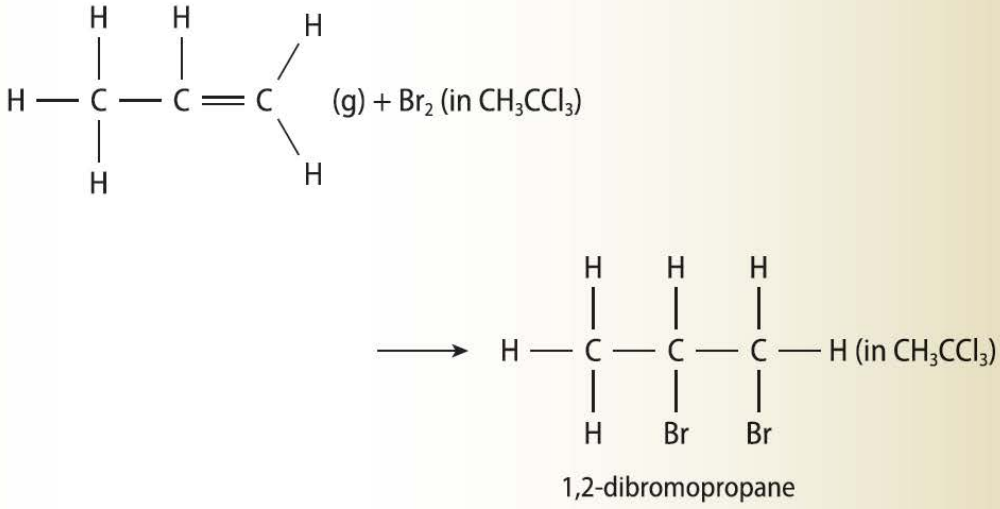
Summary (p.123)

3 a) The melting and boiling points of alkenes are very close to those of the corresponding alkanes.
b) Alkenes are insoluble in water.

4 Most reactions of the alkenes are examples of addition reactions. An addition reaction is one where two or more molecules react to form a single, larger molecule.

Summary (p.123)

5 The following table summarises two addition reactions of alkenes. These reactions can be used as tests for unsaturated compounds.

Reaction of alkene with	Observation	Example
bromine dissolved in 1,1,1-trichloroethane	the orange solution of bromine dissolved in an organic solvent becomes colorless quickly	 1,2-dibromopropane
cold acidified dilute potassium permanganate solution	the purple solution of potassium permanganate becomes colorless quickly	 ethene ethane-1,2-diol

Unit Exercise (p.125)

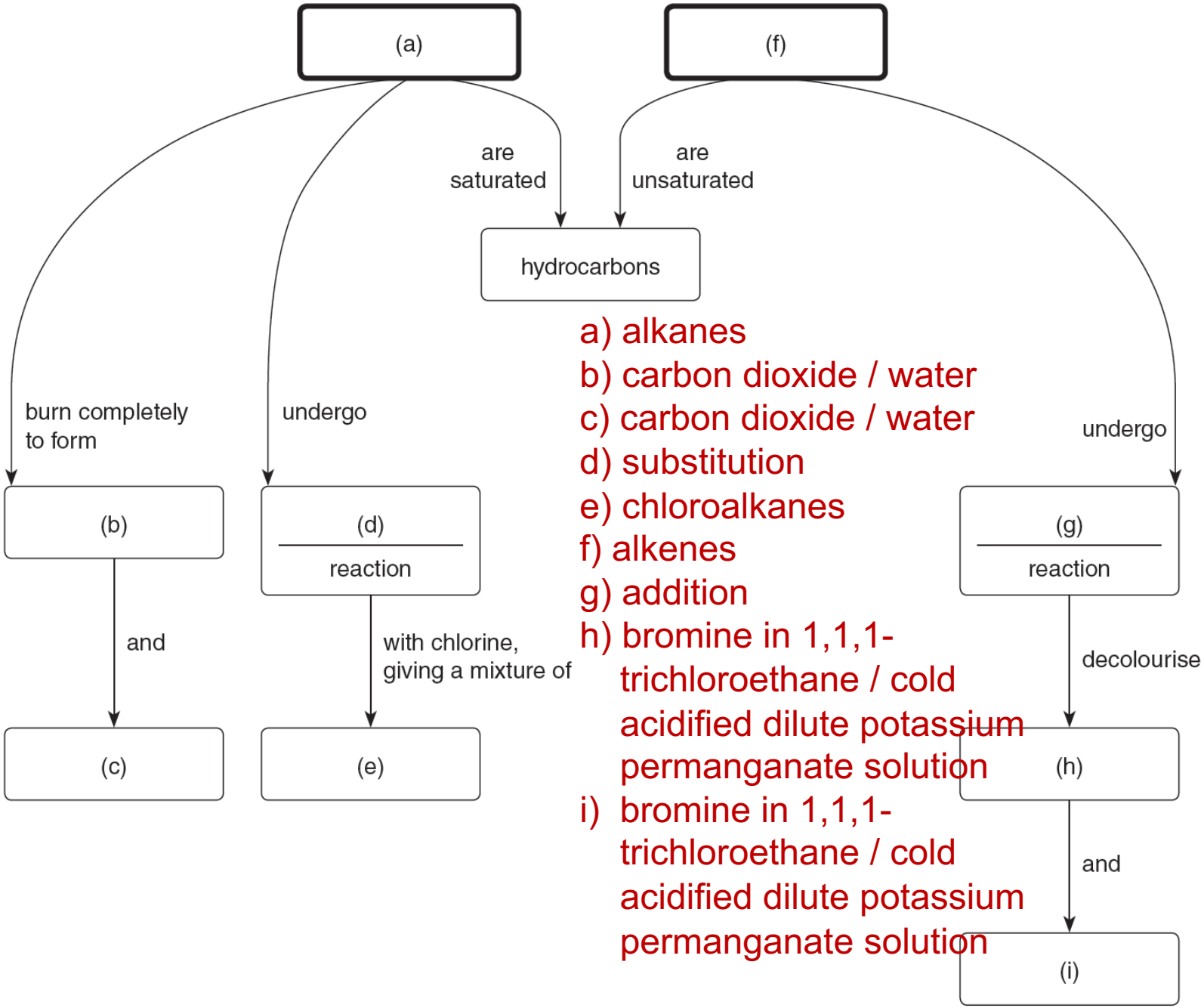
Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**
 **question targeted at level 4 and above;**
 **question targeted at level 5.**
‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.125)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



a) alkanes
b) carbon dioxide / water
c) carbon dioxide / water
d) substitution
e) chloroalkanes
f) alkenes
g) addition
h) bromine in 1,1,1-trichloroethane / cold acidified dilute potassium permanganate solution
i) bromine in 1,1,1-trichloroethane / cold acidified dilute potassium permanganate solution

Unit Exercise (p.125)

PART II MULTIPLE CHOICE QUESTIONS

2 Propane (C_3H_8) undergoes incomplete combustion in a limited amount of air. Which products are most likely to be formed during this reaction?

A Carbon monoxide and water
B Carbon monoxide and hydrogen
C Carbon dioxide and hydrogen
D Carbon dioxide and water

Answer: A

Unit Exercise (p.125)

3 One mole of methane is allowed to react with two moles of chlorine in the presence of light. Which of the following best describes the organic product(s) that would be formed?

A One mole of CCl_4
B One mole of CH_2Cl_2
C A mixture containing only CCl_4 and CH_2Cl_2
D A mixture containing CH_3Cl, CH_2Cl_2, $CHCl_3$, and CCl_4

(HKDSE, Paper 1A, 2014, 10)

Answer: D

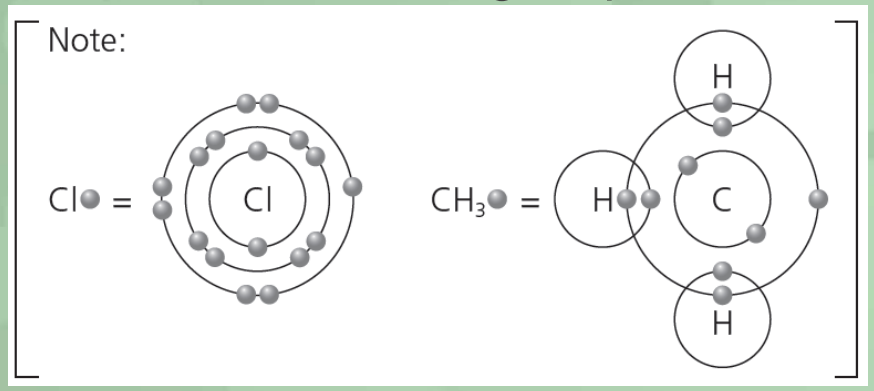
Unit Exercise (p.125)

4 The reaction below involves several steps.

$$CH_4(g) + Cl_2(g) \xrightarrow{\text{sunlight}} CH_3Cl(g) + HCl(g)$$

Which of the following steps can lead to a termination of the reaction?

Note:



A $Cl_2 \rightarrow 2Cl\bullet$
B $CH_3\bullet + Cl\bullet \rightarrow CH_3Cl$
C $CH_4 + Cl\bullet \rightarrow CH_3\bullet + HCl$
D $CH_3\bullet + Cl_2 \rightarrow CH_3Cl + Cl\bullet$

Answer: B

(HKDSE, Paper 1A, 2018, 13)

Unit Exercise (p.125)

5 Which of the following statements about cracking of alkanes is INCORRECT?

A It is an exothermic process.
B It involves breaking and forming of covalent bonds.
C It produces extra petrol.
D It involves a chemical change.

Answer: A

Explanation:
Cracking takes in heat. It is NOT an exothermic process.

Unit Exercise (p.125)

6 Upon cracking, one molecule of dodecane ($C_{12}H_{26}$) gives one molecule of ethene, one molecule of propene and one molecule of alkane X. What is X?

A C_7H_{14}
B C_7H_{16}
C $C_{10}H_{20}$
D $C_{10}H_{22}$

Answer: B

Explanation:
$C_{12}H_{26} \rightarrow X + C_2H_4 + C_3H_6$
$\therefore$ X is C_7H_{16}.

Unit Exercise (p.125)

7 Hydrocarbons with large molecules can be cracked to produce hydrocarbons with smaller molecules.
The equation shows the reaction of a hydrocarbon, $C_{10}H_{22}$.

$$C_{10}H_{22} \rightarrow C_4H_{10} + 2C_3H_6$$

Comparing $C_{10}H_{22}$ with the other hydrocarbons shown in the equation, which of the following combinations is correct?

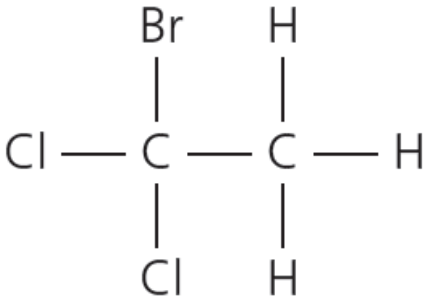
Answer: B

	Boiling point	Flammability
A	highest	highest
B	highest	lowest
C	lowest	highest
D	lowest	lowest

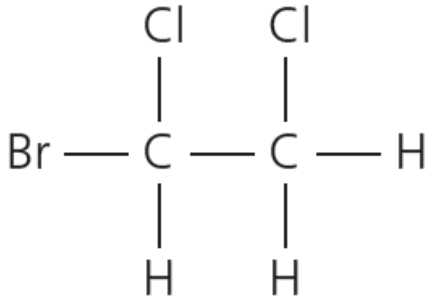
Unit Exercise (p.125)

8 Which of the following compounds would be formed when bromoethene reacts with chlorine in a suitable organic solvent?

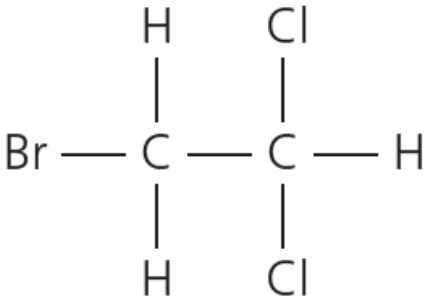
A



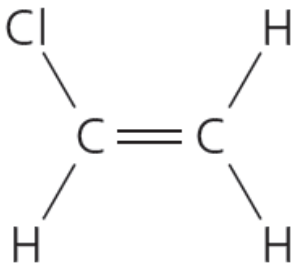
B



C



D

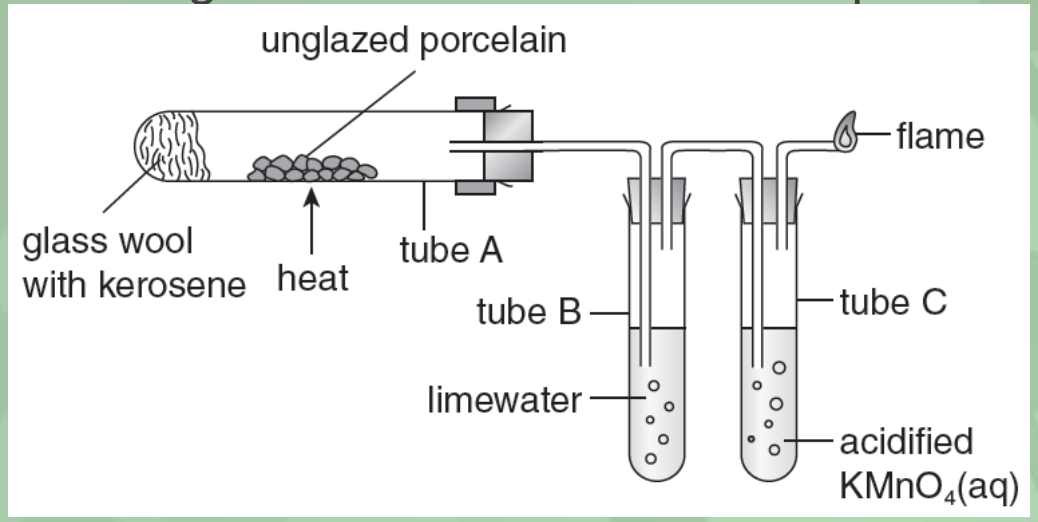


Answer: B

(HKDSE, Paper 1A, 2014, 8)

Unit Exercise (p.125)

9 The diagram below shows the set-up of an experiment:



Answer: B

Explanation:
The cracking process does NOT produce carbon dioxide. Thus, there is NO observable change in the limewater in tube B.

The unglazed porcelain in tube A is strongly heated and the glass wool is occasionally heated. Which of the following statements is correct?

A A chemical reaction occurs at the glass wool.
B There is no observable change in the limewater in tube B.
C There is no observable change in the acidified $KMnO_4(aq)$ in tube C.
D The flame is brick-red in colour.

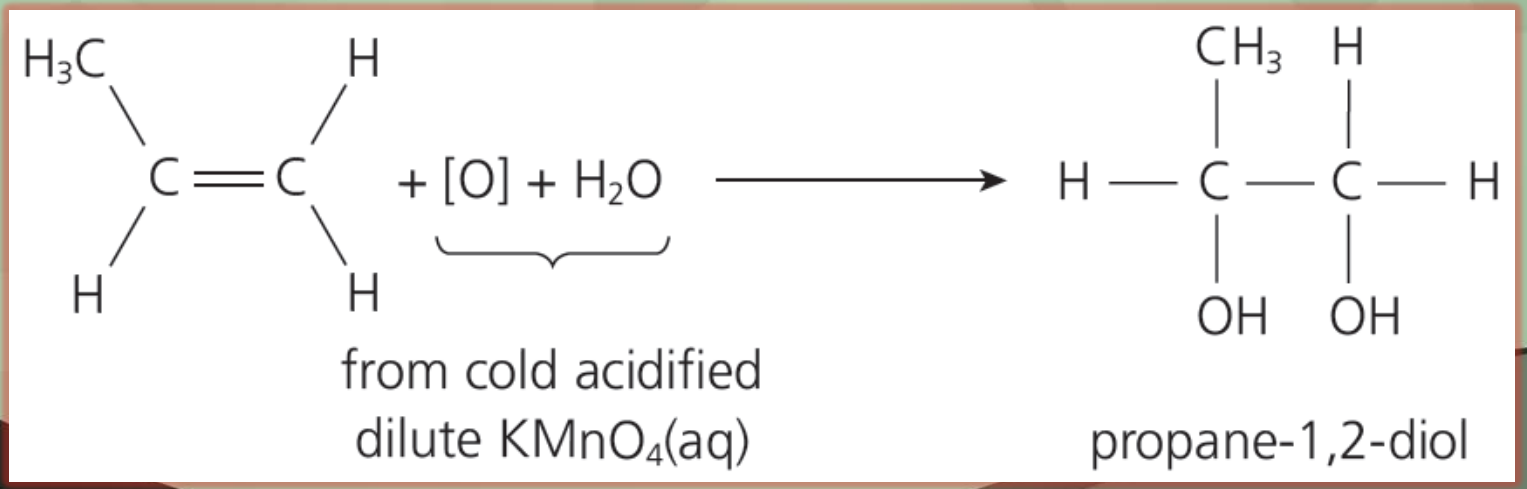
Unit Exercise (p.125)

10 Which of the following would be formed when propene reacts with cold acidified dilute KMnO4(aq)?

A Propene-1,2-diol
B Propane-1,2-diol
C A mixture of propen-1-ol and propen-2-ol
D A mixture of propan-1-ol and propan-2-ol

Answer: B

Explanation:



Unit Exercise (p.125)

11 Ethane reacts with bromine under suitable conditions. Which of the following statements concerning this reaction are correct?

(1) The reaction occurs readily in the dark.
(2) The reaction is a substitution reaction.
(3) The colour of the reaction mixture fades.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: C

Explanation:
(1) The reaction between ethane and bromine does NOT occur in the dark.

Unit Exercise (p.125)

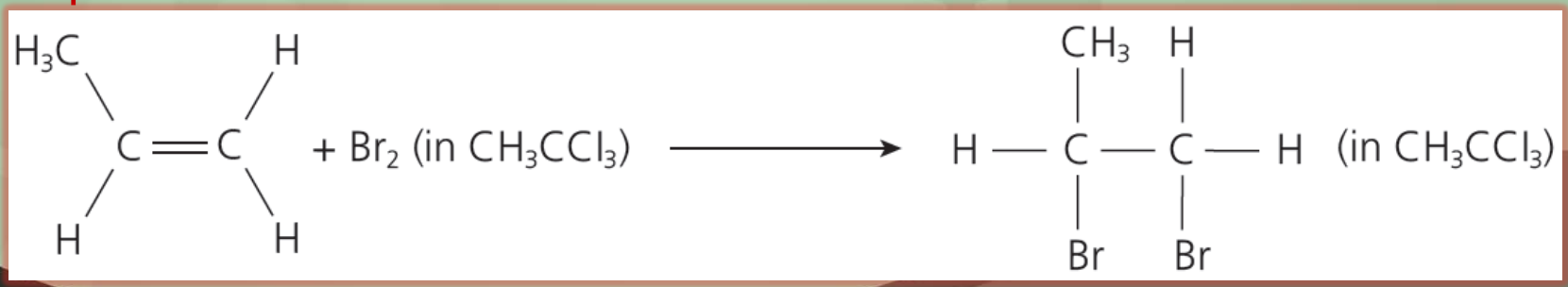
12 Which of the following statements concerning the reaction between bromine (in CH_3CCl_3) solution and excess propene are correct?

(1) An addition reaction occurs.
(2) The bromine solution becomes colourless quickly.
(3) The structural formula of the organic product is $CHBr_2CH_2CH_3$.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: A

Explanation:



Unit Exercise (p.125)

13 Which of the following statements concerning but-2-ene are correct?

(1) It is an unsaturated hydrocarbon.
(2) It has the same molecular formula as but-1-ene.
(3) It can decolourise acidified potassium dichromate solution.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: A

Explanation:
(2) The molecular formula of both but-1-ene and but-2-ene is both C_4H_8.
(3) But-2-ene has NO reaction with acidified potassium dichromate solution.

Unit Exercise (p.125)

14 Which of the following statements concerning propane and propene are correct?

(1) Both are gases at room temperature.
(2) Both are insoluble in water.
(3) Propane burns with a cleaner flame than propene.

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: D

Explanation:
(3) A propane molecule has a lower carbon to hydrogen ratio than a propene molecule. Propane undergoes complete combustion more readily.

Unit Exercise (p.125)

15 Which of the following are renewable energy sources?

(1) Nuclear energy
(2) Tidal energy
(3) Biomass

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

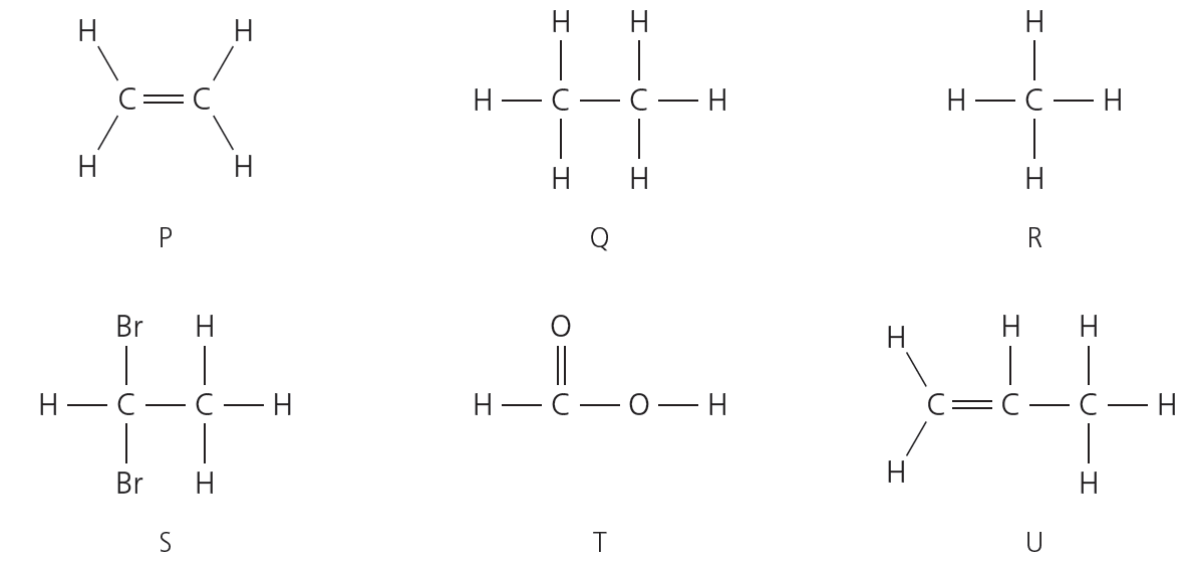
Answer: C

(HKDSE, Paper 1A, 2015, 22)

Unit Exercise (p.125)

PART III STRUCTURED QUESTIONS

16 The structural formulae of six carbon compounds are shown below.



a) i) Give the letters of TWO compounds that are unsaturated. P and U (1)

ii) Name the homologous series to which these two compounds belong.

Alkenes (1)

iii) What is the general formula of this homologous series? C_nH_{2n} (1)

b) What is the empirical formula of compound S?

CH_2Br (1)

Unit Exercise (p.125)

17 Ethane reacts with chlorine to form chloroethane (C_2H_5Cl).

$C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$

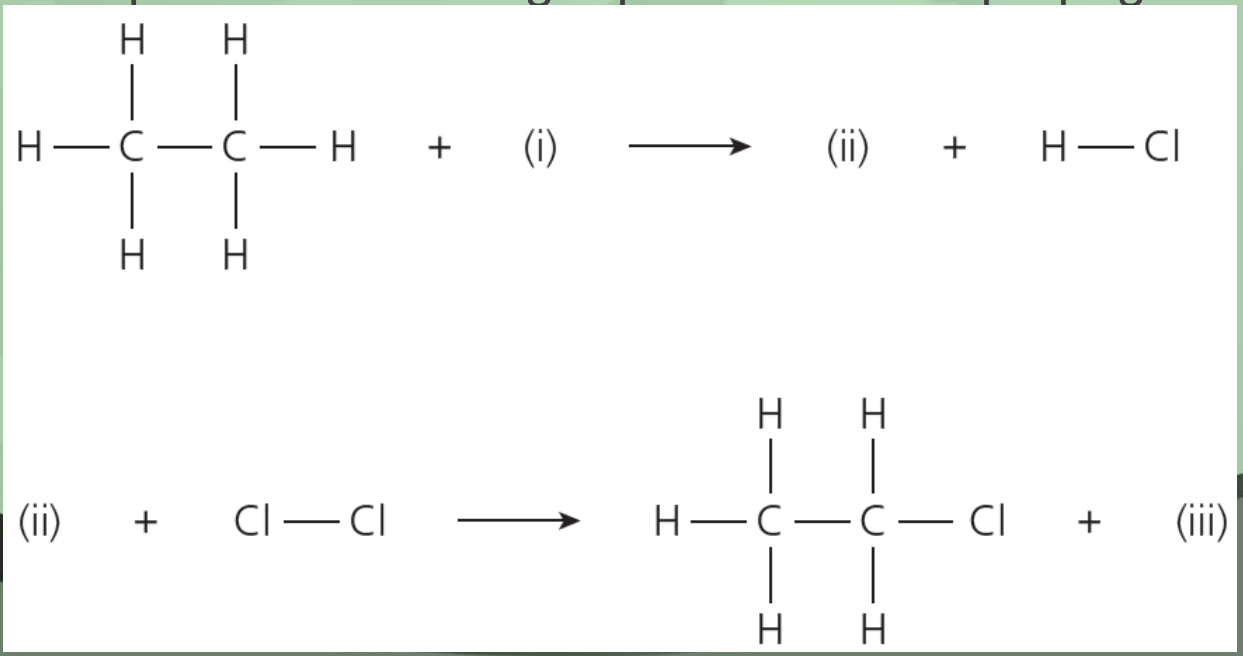
The reaction is initiated by the formation of chlorine free radicals from chlorine molecules.

a) What is the essential condition for the reaction?

Ultraviolet light / heat / radical initiator (1)

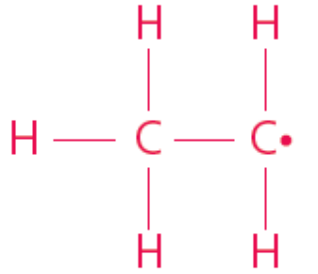
b) The chlorine free radicals react with ethane to produce C_2H_5Cl.

Complete the following equations for the propagation steps involved.



i) •Cl (1)

ii)



(1)

iii) •Cl (1)

Unit Exercise (p.125)

c) Besides chloroethane, name ONE other chlorine-containing organic product which is formed in the reaction.

Accept dichloroethanes, trichloroethanes, etc. (1)

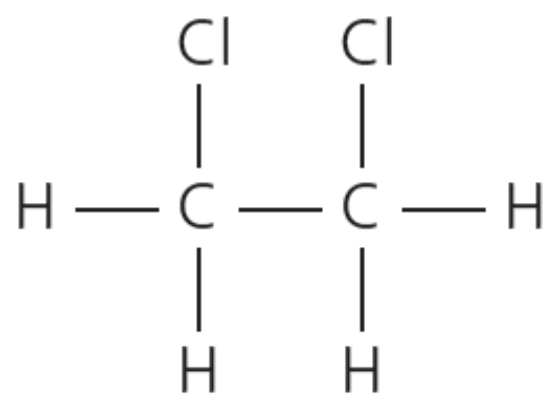
d) Butane is a trace product of this reaction. Suggest how the butane is formed.

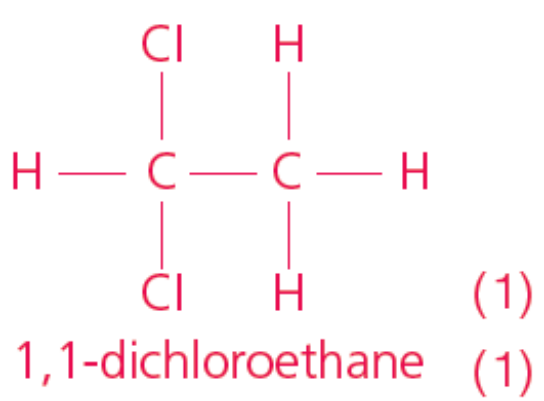
Two ethyl radicals react together to give a butane molecule. (1)

Unit Exercise (p.125)

18 1,2-dichloroethane can be made by the chlorination of ethane.
The reaction between ethane and chlorine is carried out using electromagnetic radiation and produces 1,2-dichloroethane together with other chlorine-containing organic products.

a) What type of electromagnetic radiation is used? Ultraviolet radiation (1)
b) Name the type of reaction involved? Substitution reaction (1)
c) The structural formula of 1,2-dichloroethane is shown below.
Write the structural formula of the other dichloroethane formed. Give its systematic name.





Unit Exercise (p.125)

d) Suggest why the reaction between ethane and chlorine is NOT used to produce 1,2-dichloroethane commerically.

Any one of the following:
- Many chlorinated products are formed. (1)
- The yield is low. (1)
- It is difficult / costly to separate the product from the mixture. (1)

Unit Exercise (p.125)

19 Petrol is a commonly used motor car fuel. It can be obtained from petroleum by fractional distillation.

a) Other than directly obtaining petrol from fractional distillation of petroleum, suggest a way for producing extra petrol.

Cracking of heavy oil / heavy hydrocarbons (1)

b) Octane is a component of petrol.

i) Write the chemical equation for the complete combustion of octane.

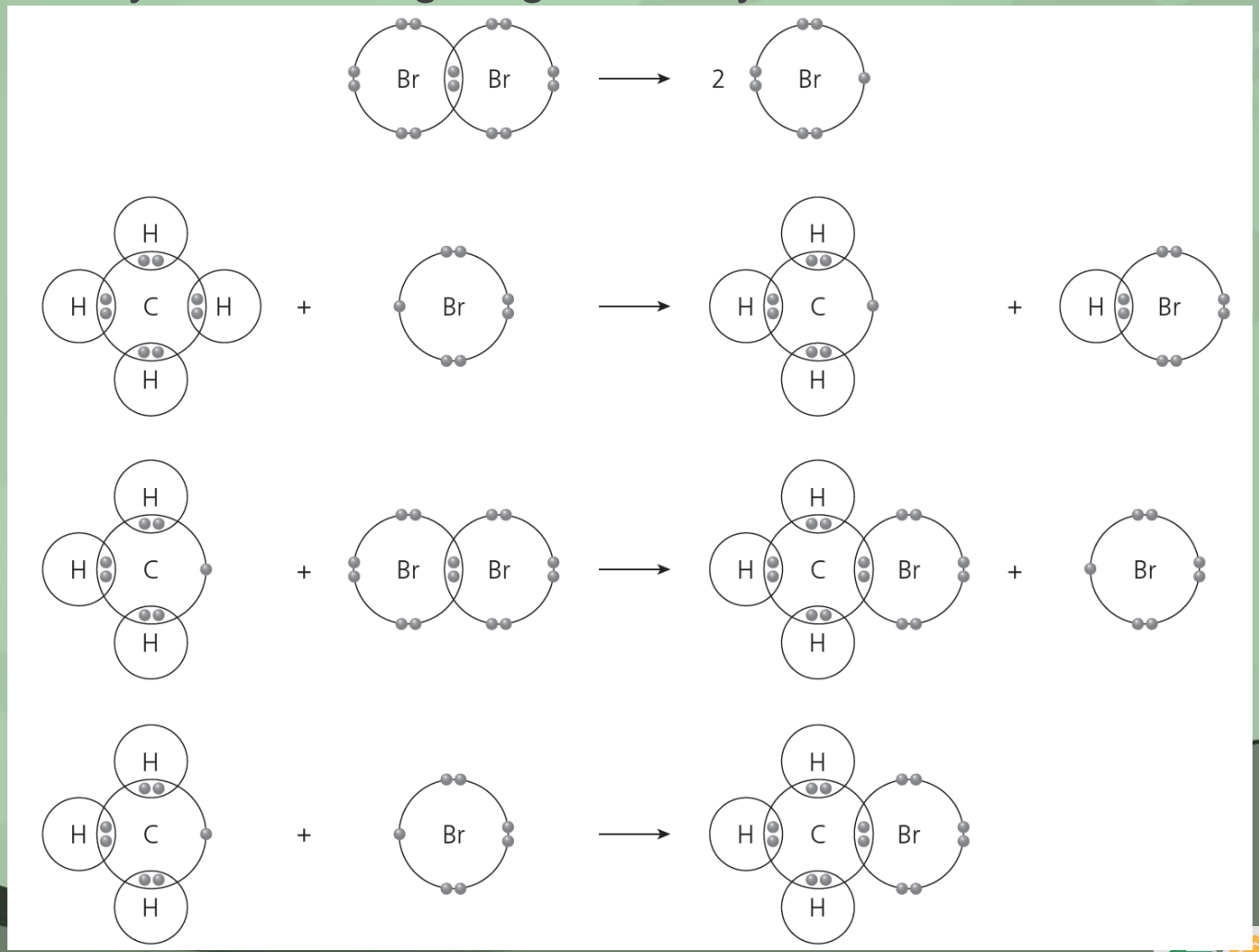
$2C_8H_{18}(g / l) + 25O_2(g) \rightarrow 16CO_2(g) + 18H_2O(l)$ (1)

ii) The incomplete combustion of octane produces a poisonous gas that reduces the capacity of blood to carry oxygen. Write the chemical equation for this incomplete combustion of octane.

$2C_8H_{18}(g / l) + 17O_2(g) \rightarrow 16CO(g) + 18H_2O(l)$ (1)

Unit Exercise (p.125)

20 The steps involved in the reaction of methane with bromine forming CH_3Br can be shown by the following diagram. Only electrons in the *outermost shells* are shown.



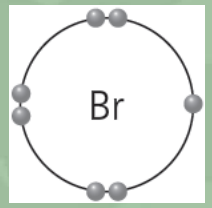
Unit Exercise (p.125)

a) Name the type of the reaction for the formation of CH_3Br from methane and bromine.

b) State the condition needed for the reaction to occur.

c) State the expected observation for the reaction.

d) With reference to its electronic structure, explain why the species has a high reactivity.



e) The reaction of methane with bromine can also form other single-carbon-containing organic compounds.

i) Suggest ONE such compound.

ii) Suggest a condition so that the reaction of methane with bromine can form more CH_3Br but less other organic compounds.

(HKDSE, Paper 1B, 2015, 6)

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Unit Exercise (p.125)

21 Dodecane ($C_{12}H_{26}$) is an alkane. Dodecane can be cracked to form octane and one other hydrocarbon.

a) Describe how cracking is carried out.

Heat to vaporise dodecane. (1)

Pass the vapour over a catalyst. (1)

b) Complete the equation that represents this cracking reaction.

$C_{12}H_{26} \rightarrow C_8H_{18} + 2$ C_2H_4 (1)

c) When cracking takes place, a large number of different products are formed.

Suggest why a large number of different products are formed.

Any carbon-carbon bond in an alkane molecule can break. (1)

Unit Exercise (p.125)

22 The alkanes are a family of saturated hydrocarbons. Their reactions include combustion, cracking and substitution.

a) i) What is meant by the term 'hydrocarbon'?

A hydrocarbon is a compound containing only hydrogen atoms and carbon atoms. (1)

ii) What is meant by the term 'saturated'?

In a saturated hydrocarbon, all the carbon-carbon bonds in the hydrocarbon molecule are single covalent bonds. (1)

b) What is the general formula for the homologous series of alkanes?

C_nH_{2n+2}

c) The complete combustion of hydrocarbons produces carbon dioxide and water only. Write the equation for the complete combustion of nonane, C_9H_{20}.

$C_9H_{20}(g / l) + 14O_2(g) \rightarrow 9CO_2(g) + 10H_2O(l)$ (1)

Unit Exercise (p.125)

d) Cracking is used to obtain short-chain alkanes, alkenes and hydrogen from long-chain alkanes.

i) Give a use for each of the three products listed above.

(1) short-chain alkanes In petrol / fuel / solvent (1)

(2) alkenes To make alcohols / plastics / polymers / solvents (1)

(3) hydrogen To make ammonia / fuel for fuel cell (1)

ii) Write an equation for the cracking of decane, $C_{10}H_{22}$, which produces two different alkenes and hydrogen as the only products.

Example: $C_{10}H_{22} \rightarrow C_8H_{16} + C_2H_4 + H_2$ (1) / Accept other correct equation

e) Chlorine reacts with propane in a substitution reaction to form 1-chloropropane: $CH_3CH_2CH_3 + Cl_2 \rightarrow CH_3CH_2CH_2Cl + HCl$

i) What is the essential condition for the above reaction?

Ultraviolet light / heat / radical initiator (1)

ii) There is more than one possible substitution reaction between chlorine and propane. Suggest the structural formula of a different product.

$CH_3CHClCH_3$ (1)

(Cambridge IGCSE, 0620/33, Paper 3, Jun. 2014, 6)

Unit Exercise (p.125)

23 Petroleum is processed to give a wide variety of hydrocarbons.

a) Give the names of ONE physical process and ONE chemical process carried out during the processing of petroleum.

b) Both alkanes and alkenes can be obtained from petroleum. Alkanes and alkenes are examples of homologous series.

i) Complete the table below.

Name of homologous series	General formula	Structural formula of compound with three carbon atoms
Alkanes	? C_nH_{2n+2} (1)	? $CH_3CH_2CH_3$ (1)
Alkenes	? C_nH_{2n} (1)	$CH_3CH=CH_2$

Unit Exercise (p.125)

ii) Give the term to describe hydrocarbons, such as alkene, containing a C=C bond. Unsaturated hydrocarbons (1)

iii) Explain why alkanes are unreactive. Strong C−C and C−H bonds (1)

iv) Suggest a chemical test, giving the expected observation, to show the presence of an alkene.

Any one of the following:

- Add an orange solution of bromine dissolved in 1,1,1-trichloroethane to an alkene. (1)
  The orange solution of bromine becomes colourless quickly. (1)
- Add a purple solution of cold acidified dilute potassium permanganate solution to an alkene. (1)
  The purple solution of potassium permanganate becomes colourless quickly. (1)

Unit Exercise (p.125)

24 The table below shows the percentage of fractions in petroleum and the demand for them.

Fraction	Approximate % in petroleum	Approximate % demand
Refinery gases	2	5
Petrol	21	28
Kerosene	13	8
Diesel	17	25
Fuel oil and bitumen	47	34

Unit Exercise (p.125)

a) The exhaust of a diesel engine contains a higher concentration of particulates than that of a petrol engine. Explain why.

The hydrocarbon molecules in diesel have a higher carbon to hydrogen ratio than those in petrol. (1)

Diesel has a greater chance to undergo incomplete combustion to give particulates. (1)

b) The low demand fractions are catalytically cracked. The general equation for some reactions in this process is

alkane → alkane + alkene

i) How does the bonding in an alkene molecule differ from the bonding in an alkane molecule? An alkene molecule has a carbon-carbon double bond while an alkane molecule has only single bonds. (1)

ii) The cracking of octadecane ($C_{18}H_{38}$) produces decane ($C_{10}H_{22}$) and one other product. Write the chemical equation for this cracking reaction.

$C_{18}H_{38} \longrightarrow C_{10}H_{22} + C_8H_{16}$ (1)

or $C_{18}H_{38} \longrightarrow C_{10}H_{22} + 2C_4H_8$ (1)

or $C_{18}H_{38} \longrightarrow C_{10}H_{22} + 4C_2H_4$ (1)

Unit Exercise (p.125)

25 Used car engine oil can be recycled for use as a fuel by the processes of distillation and cracking. A typical molecule of engine oil has the chemical formula $C_{40}H_{82}$. This molecule can be cracked to produce smaller molecules as shown in the equation below.

$$C_{40}H_{82} \rightarrow C_{16}H_{34} + 2D$$

a) Suggest a possible molecular formula of D. $C_{12}H_{24}$ (1)

b) Suggest why high temperatures are used in cracking other than to speed up the reaction.

To break the C−C and C−H bonds. / To break down the hydrocarbons. (1)

Unit Exercise (p.125)

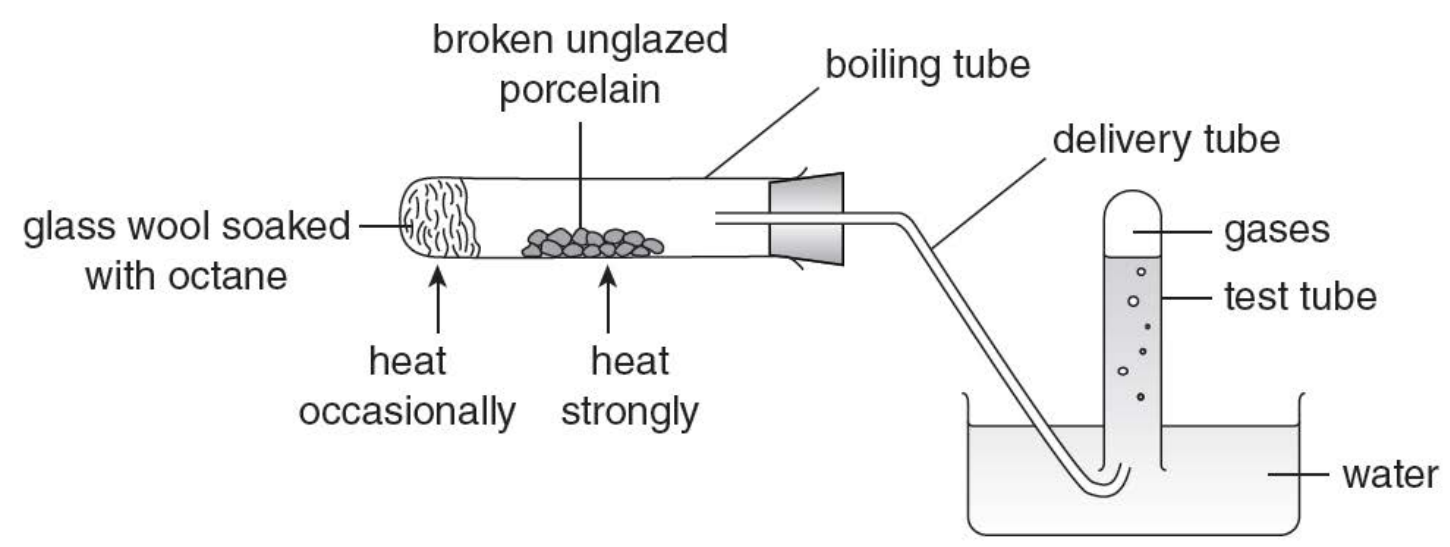
c) The compounds $C_{40}H_{82}$ and $C_{16}H_{34}$ are members of the same homologous series.
Using $C_{40}H_{82}$ and $C_{16}H_{34}$ as example, illustrate TWO characteristics of members of a homologous series.

Any two of the following:

- Members in a homologous series have the same general formula. (1)
  The general formula for $C_{40}H_{82}$ and $C_{16}H_{34}$ is C_nH_{2n+2}. /
  Each member in a homologous series differs from the next by a $–CH_2–$ unit. (1)
- Members in a homologous series have physical properties that show a graduation. (1)
  The boiling point of $C_{40}H_{82}$ is higher than that of $C_{16}H_{34}$. (1)
- Members in a homologous series have similar chemical properties. (1)
  Both $C_{40}H_{82}$ and $C_{16}H_{34}$ undergo substitution reaction with chlorine. (1)

Unit Exercise (p.125)

26 The diagram below shows an experimental set-up in which the glass wool soaked with octane is heated occasionally and the broken unglazed porcelain is heated strongly. Some gases are collected in the test tube over water.



Unit Exercise (p.125)

a) Name the type of reaction that occurs in the boiling tube. Suggest ONE importance of this type of reaction in industry.

b) Explain why, instead of a large piece of unglazed porcelain, broken unglazed porcelain is used in this experiment.

c) Suppose that during the experiment, octane changes to ethane gas and propene gas only and they can be collected in the test tube.

i) Write the balanced equation for the reaction of changing octane to ethane and propene.

ii) The gases collected in the test tube are shaken thoroughly with a few drops of Br_2 (in CH_3CCl_3) solution.

(1) State the expected observation.

(2) Draw the structure of the product formed from the reaction between propene and Br_2.

d) When no more gas can be collected, what should be done to end the experiment for safety consideration? Explain your answer.

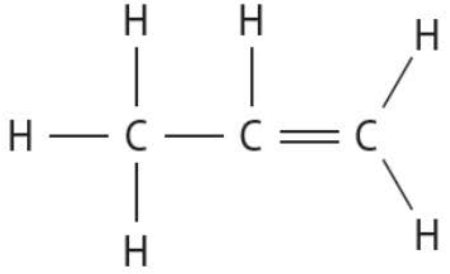
(HKDSE, Paper 1B, 2016, 3)

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Unit Exercise (p.125)

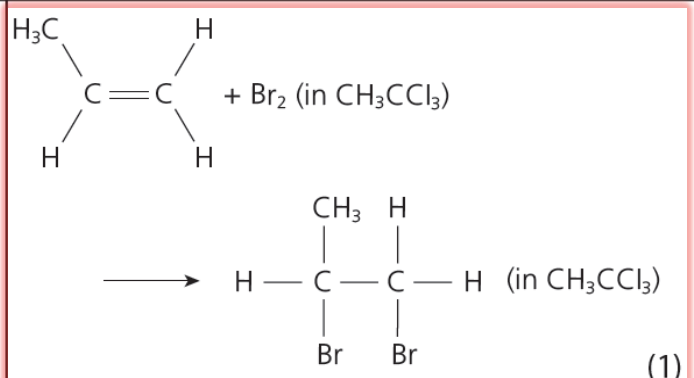
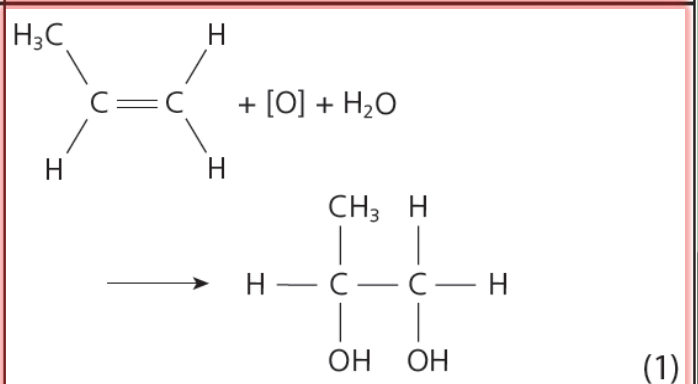
27 A teacher explained the different types of formulae used in carbon chemistry, using propene as an example.

a) Complete the table below.

Description	Formula
General	C_nH_{2n} (1)
Molecular	C_3H_6
Structural	
Skeletal	 (1)

Unit Exercise (p.125)

For each of the following reactions involving propene, state the expected observation and write a chemical equation.

Reaction	Expected observation	Chemical equation
(i) Add a few drops of bromine (in CH_3CCl_3) solution to propene	The orange solution of bromine becomes colourless quickly (1)	 (1)
(ii) Add a few drops of cold acidified potassium permanganate solution to propene	The purple solution of potassium permanganate becomes colourless quickly (1)	 (1)

Unit Exercise (p.125)

28 Cracking is an important process in the petrochemical industry.

a) What is the meaning of the term 'cracking'?

Cracking is the breaking down of large hydrocarbon molecules with heat or in the presence of a catalyst to produce smaller hydrocarbon molecules. (1)

b) Account for the importance of cracking in the petrochemical industry.

- To produce alkenes which can make a huge range of other compounds. (1)
- To convert heavy oil to petrol. (1)

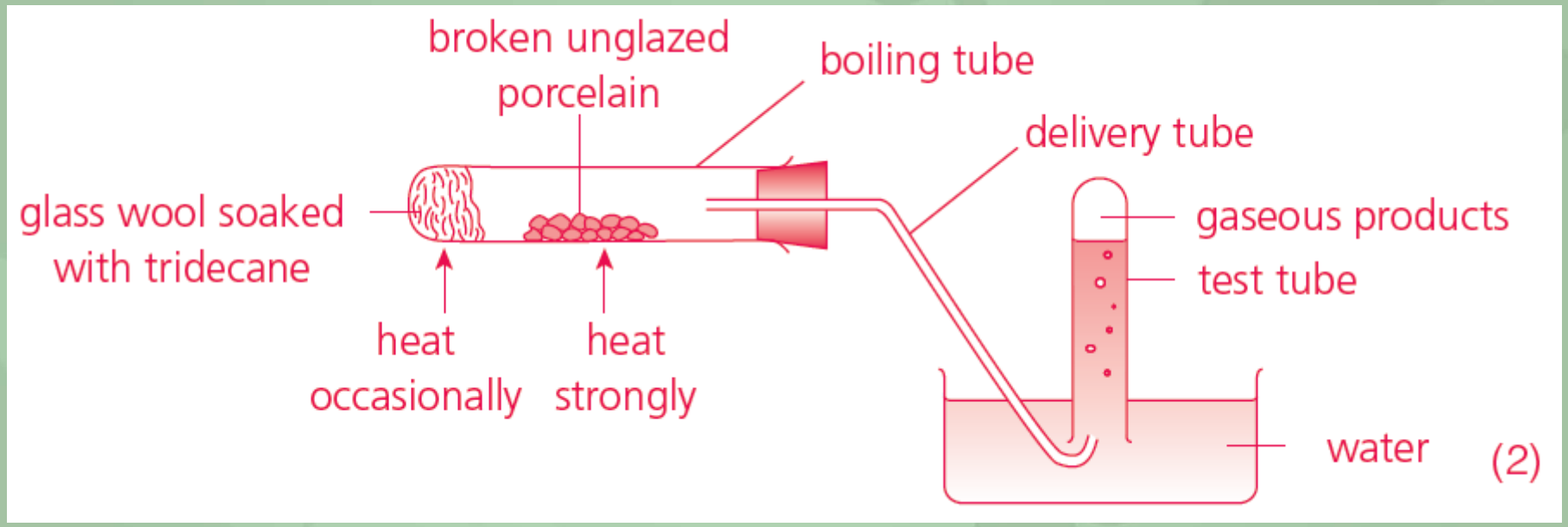
c) Tridecane ($C_{13}H_{28}$) is used in an experiment to study cracking in a school laboratory.

i) In one cracking reaction, tridecane forms octane and two alkenes. Complete the equation to show the molecular formulae of the two alkenes.

$$C_{13}H_{28} \rightarrow C_8H_{18} + \underline{\quad C_2H_4 \quad} + \underline{\quad C_3H_6 \quad} \text{ (1)}$$

Unit Exercise (p.125)

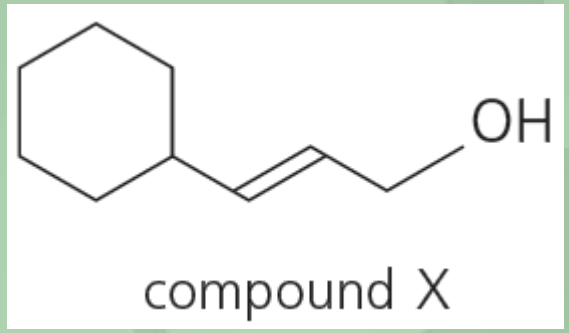
ii) Draw a labelled diagram for the set-up used in the experiment, including the collection of the gaseous products.



(2)

Unit Exercise (p.125)

29 A structure of compound X is shown below.



compound X

a) Name TWO functional groups found in compound X.

Carbon-carbon double bond (1)

Hydroxyl group (1)

b) The structure of compound X is shown above as a skeletal formula. Give the molecular formula of compound X.

$C_9H_{16}O$ (1)

Unit Exercise (p.125)

c) Compound X is an unsaturated compound.

i) What is the meaning of the term 'unsaturated'? A compound containing carbon-carbon double bond / carbon-carbon multiple bond (1)

ii) Describe a test to show that X is an unsaturated compound.

Any one of the following:

• Add an orange solution of bromine dissolved in 1,1,1-trichloroethane to X. (1)
The orange solution of bromine becomes colourless quickly. (1)

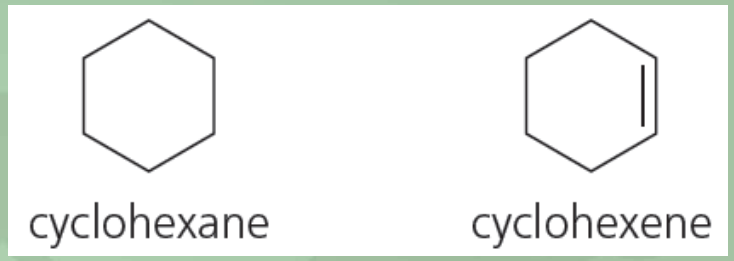
• Add a purple solution of cold acidified dilute potassium permanganate solution to X. (1)
The purple solution of potassium permanganate becomes colourless quickly. (1)

d) After some lessons in carbon chemistry, a student made the following statement: 'Alkenes react with chlorine while alkanes do not.'
Do you agree with the student? Explain.

The student is wrong.
Alkenes react with chlorine in the dark by addition reaction. (1)
Alkenes react with chlorine under sunlight by free radical substitution. (1)

Unit Exercise (p.125)

30 The chemical properties of cyclohexane and cyclohexene are different.



Design experiments to show how they differ in their reactions with oxygen in air and their reactions with bromine. Explain the differences.

Reaction with oxygen in air

Burn cyclohexane and cyclohexene on watch glasses separately. (1)

Cyclohexane gives a less sooty flame. / Cyclohexene gives a more sooty flame. (1)

Cyclohexane molecule has a lower carbon to hydrogen ratio than cyclohexene molecule. Cyclohexane burns more completely. (1)

Reaction with bromine

Add an orange solution of bromine (in CH_3CCl_3) to cyclohexane and cyclohexene in test tubes separately. (1)

The orange bromine solution becomes colourless quickly in cyclohexene. The orange bromine solution becomes colourless slowly when added to cyclohexane in the presence of ultraviolet light / heat. (1)

Cyclohexene undergoes an addition reaction with bromine while cyclohexane undergoes a substitution reaction with bromine in the presence of ultraviolet light / heat. (1) Communication mark (1)