Alkanes

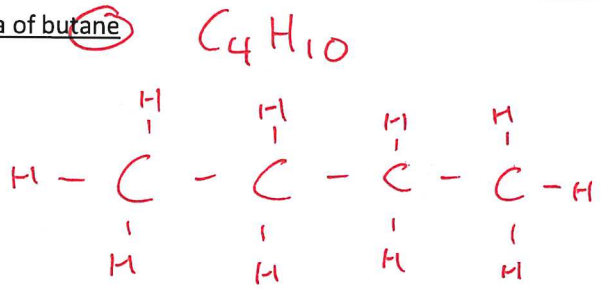
Alkanes are a family of **hydrocarbons**. This means that they share certain characteristics in common such as chemical properties. They are **Saturated** hydrocarbons because they contain only single bonds.

Butane is one of the molecules in the alkane family.

It has the molecular formula C_4H_{10}. The **molecular formula** only tells us the number of atoms of each element in a molecule. There are 4 carbon atoms and 10 hydrogen atoms in a molecule of butane.

Instead, we can use the **displayed formula** to show us the structure of the molecule.

Displayed formula of butane



- Each line represents 1 covalent bond (one pair of shared electrons).
- Each carbon atom has 4 covalent bonds to other atoms.
- Each hydrogen atom has 1 covalent bond to another atom.

Naming Alkanes (Prefixes)

Butane is the fourth molecule in the alkane family. The "but-" part of the name refers to the fact that in the molecule there are 4 carbons in the longest chain (continuous line of carbon atoms).

Number of Carbon Atoms in the Chain	Name of hydrocarbon	To help you remember
1	**Meth-**	**Monkeys**
2	**Eth-**	**Eat**
3	**Prop-**	**Peanut**
4	**But-**	**Butter**
5	**Pent-**	**Pentagon**
6	**Hex-**	**Hexagon**
7	**Hept-**	**Heptagon**
8	**Oct-**	**Octagon**
9	**Non-**	**Nonagon**
10	**Dec-**	**Decagon**

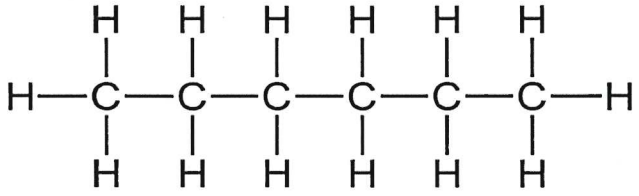
Task: Look at the displayed formulae and use the naming alkanes table to fill in the blanks

Number of carbons = 6

Number of hydrogens = 14

Molecular formula = C_6H_{14}

Name of alkane = Hexane

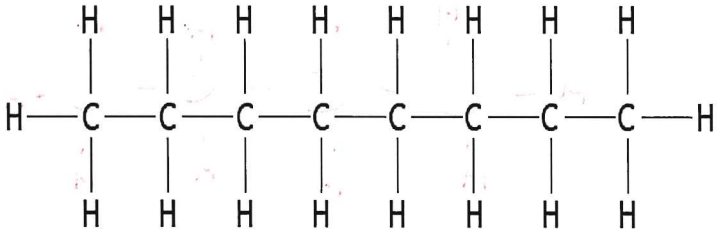


Number of carbons = 8

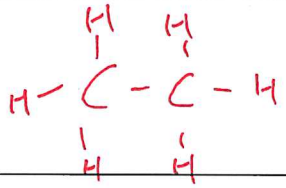
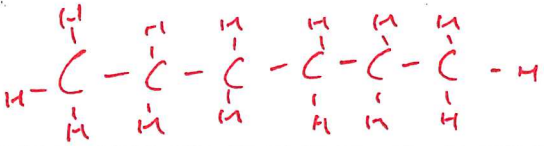
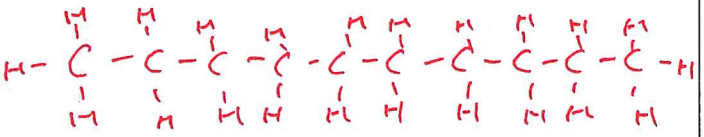
Number of hydrogens = 18

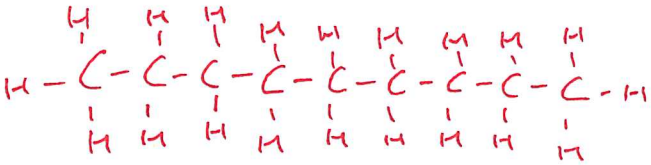
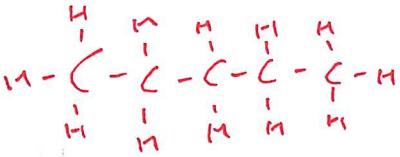
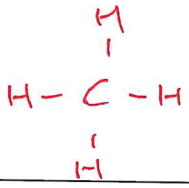
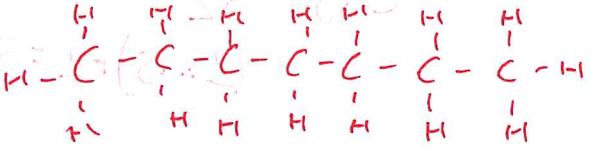
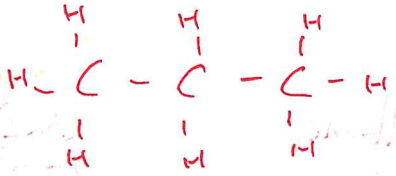
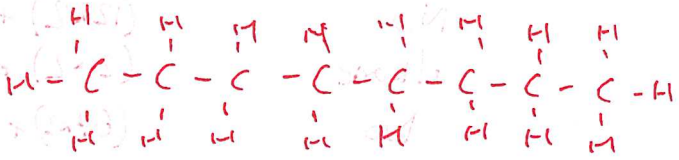
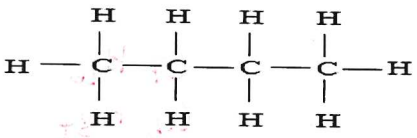
Molecular formula = C_8H_{18}

Name of alkane = Octane



Task: Use the molymods to build the first ten alkanes and then use their structures to help you complete the table.

Number of carbons	Alkane	Molecular formula	Displayed formula
2	Ethane	C_2H_6	
6	Hexane	C_6H_{14}	
10	Decane	$C_{10}H_{22}$	

9	Nonane	C_9H_{20}	
5	Pentane	C_5H_{12}	
1	Methane	CH_4	
7	Heptane	C_7H_{16}	
3	Propane	C_3H_8	
8	Octane	C_8H_{18}	
4	Butane	C_4H_{10}	

General formula for alkanes

The molecular formula for methane is CH_4. In 1 molecule of methane there is 1 carbon atom and 4 hydrogen atoms. We can represent this molecular formula using a general formula which is the same for all alkanes.

The **general formula** for alkanes is: C_nH_{2n+2} If there are *n* carbons, there are $2n + 2$ hydrogens.

Example 1

A hydrocarbon has a molecule formula of C_8H_{16}. Is the molecule an alkane? NO

$C_8H_{(2\times8)+2} = C_8H_{18}$

Example 2

If there are fifteen carbons atoms in an alkane molecule, what is the molecular formula?

$C_{15}H_{32}$

$(2\times15)+2=32$

Task: Use the general formula to answer the following questions.

1) Use the general formula to deduce (work out) which of the following molecular formula are alkanes

a) C_3H_8 ..... alkane ..... $(3\times2)+2=8$

b) C_5H_{10} ..... No ..... $(5\times2)+2=12$

c) $C_{12}H_{28}$ ..... No ..... $(12\times2)+2=26$

d) $C_{21}H_{44}$ ..... alkane ..... $(21\times2)+2=44$

e) $C_{67}H_{130}$ ..... No ..... $(67\times2)+2=136$

2) Use the general formula to deduce (work out) the molecular formula the alkane given the number of carbon atoms

a) 7 carbon atoms ..... C_7H_{16} ..... $(7\times2)+2=16$

b) 16 carbon atoms ..... $C_{16}H_{34}$ ..... $(16\times2)+2=34$

c) 29 carbon atoms ..... $C_{29}H_{60}$ ..... $(29\times2)+2=60$

d) 46 carbon atoms ..... $C_{46}H_{94}$ ..... $(46\times2)+2=94$

e) 72 carbon atoms ..... $C_{72}H_{146}$ ..... $(72\times2)+2=146$

Empirical formulae

The **empirical formula** shows the simplest whole number ratio of atoms present in a compound.

So the molecular formula is a multiple of the empirical formula.

TASK: Complete the following table of molecular and empirical formulae:

Molecular formula		Empirical formula
C_2H_6	2:6 → 1:3	CH_3
$C_{10}H_{22}$	10:22	$C_{10}H_{22}$
CH_4	1:4	CH_4
C_9H_{20}	9:20	C_9H_{20}
C_3H_8	3:8	C_3H_8
C_8H_{18}	8:18 → 4:9	C_4H_9
C_4H_{10}	2:5	C_2H_5
C_7H_{16}	7:16	C_7H_{16}
C_5H_{10}	1:2	CH_2
C_6H_{12}	1:2	CH_2
C_2H_4	1:2	CH_2
C_3H_6		CH_2

Alkenes

Tick the ones in the table which are alkanes.

C_nH_{2n+2}

What other information might tell you how to "unsimplify" an empirical formula into a molecular formula?

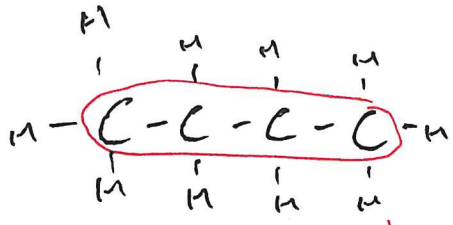
Isomers

Keyword definition

A molecule with the same **molecular** formula but different **displayed** formula.

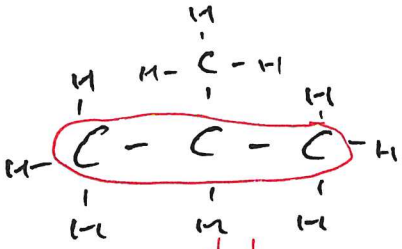
For example C_4H_{10} has two isomers.

Isomer 1



Butane

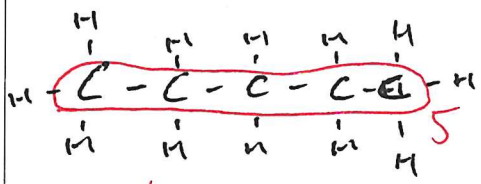
Isomer 2



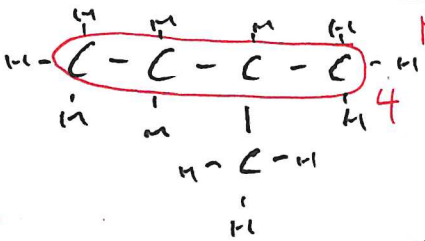
Methylpropane

Task: Use the Molymods to draw the displayed formulae for the isomers of C_5H_{12} and C_6H_{14}

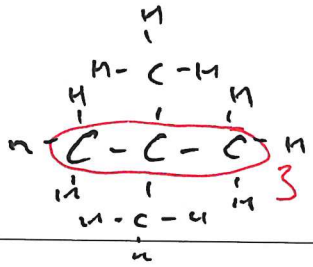
Isomers of C_5H_{12}



Pentane



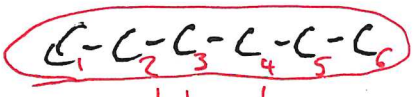
Methyl butane



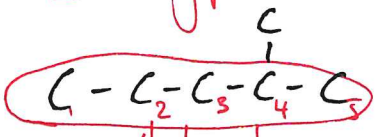
dimethylpropane

Isomers of C_6H_{14}

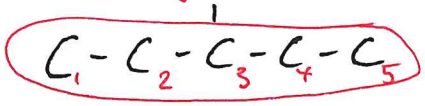
Hexane

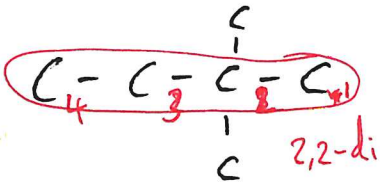


2-methylpentane

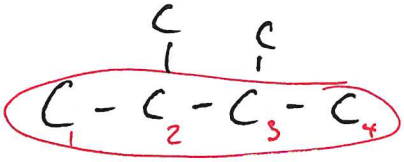


3-methylpentane





2,2-dimethylbutane



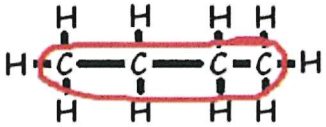
2,3-dimethylbutane

Naming isomers

Isomers of butane C_4H_{10}

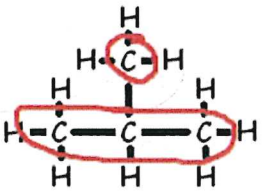
Rule 1 – Name the longest continuous chain of carbon atoms, and end it with **–ane.**

- The longest chain is 4 carbons, so **butane**.



Rule 2 – Remaining side chains will be given the ending **–yl**. They are placed before the longest chain when naming.

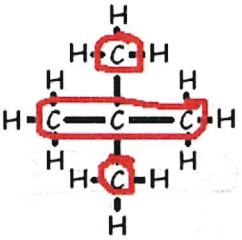
- The longest chain is 3 carbons, so propane.
- There is one carbon left. We call this "methyl".
- Therefore **methyl propane**



Isomers of pentane, C_5H_{12}

Rule 3 - Multiple side chains will use prefixes: 2 is di-, 3 is tri-, 4 is tetra

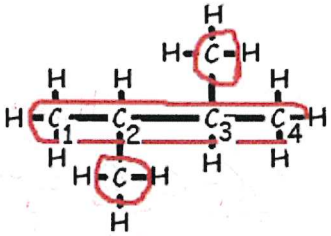
- The longest chain is 3, so propane
- There are 2 separate, one carbon side chain, so dimethyl
- Therefore the molecule is **dimethyl propane**



Isomers of hexane, C_6H_{14}

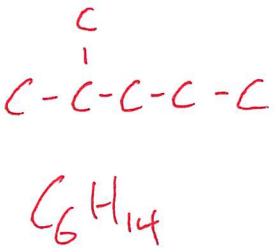
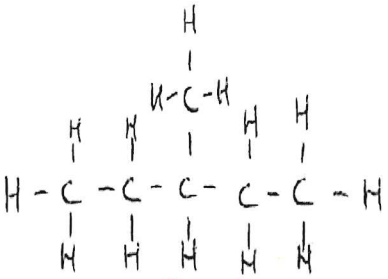
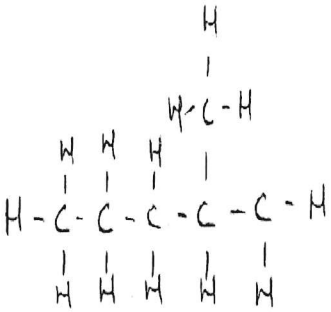
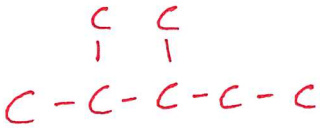
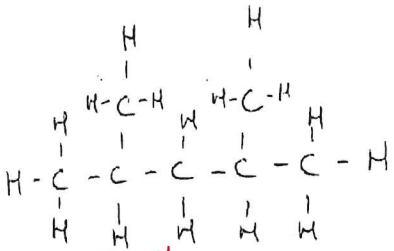
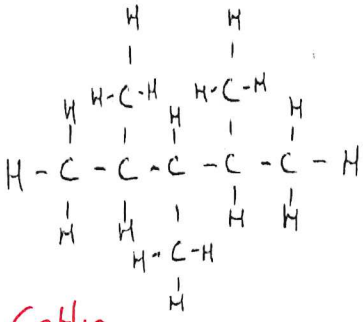
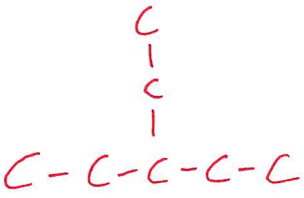
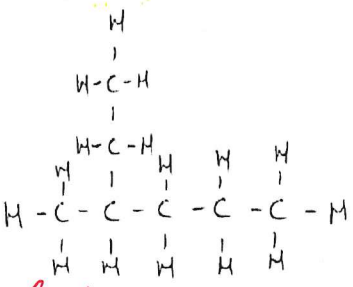
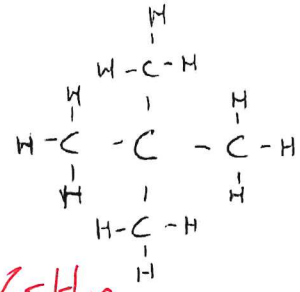
Rule 4 – When necessary use the lowest number to give the location of each side chain. You may have to number the longest chain from the right side to find the lowest number. (Note – numbers and letters are separated by a hyphen.

- The longest chain is 4, so **butane**
- There are 2 separate, one carbon side chain, so **dimethyl**
- One methyl is located on carbon 2 and the other on carbon 3, so **2,3**
- Therefore the molecule is **2,3-dimethyl butane**



Task: Use these rules to name the isomers of butane and pentane that you have drawn on the previous page.

Task: Complete the table with names, displayed formulae and molecular formulae. Every box should contain a name **AND** a displayed formula **AND** a molecular formula.

2-methylpentane  C_6H_{14}	3-methylpentane  C_6H_{14}	2-methylpentane  C_6H_{14}
2,3-dimethylpentane  C_7H_{16}	2,4-dimethylpentane  C_7H_{16}	2,3,4-trimethylpentane  C_8H_{18}
3-ethylpentane  C_7H_{16}	3-methylhexane  C_7H_{16}	dimethylpropane  C_5H_{12}

Fractional Distillation

Learning Outcomes:

1) Describe and explain how the industrial process of fractional distillation separates crude oil into fractions
2) Recall the names and uses of the main fractions obtained from crude oil
3) Describe the trend in boiling point, colour and viscosity of the main fractions

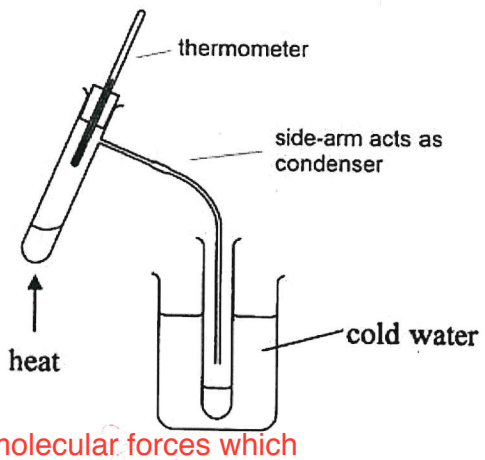
Crude oil is a mixture of different hydrocarbons. These can be separated by fractional distillation.

A **fraction** is a group of compounds that have similar boiling points.

Viscosity is a measure of how easily a fluid flows: Water has a very low viscosity (flows very easily), crude oil has a very high viscosity, (it doesn't flow easily).

Fractional distillation of crude oil in the laboratory.

The mixture is separated by heating. Each substance in the mixture has a different, fixed boiling point (T_b). The different substances obtained are called "fractions" and they each have a different colour, viscosity and flammability/volatility.



Why do larger alkanes have higher boiling points? (Think about properties of simple molecules.)

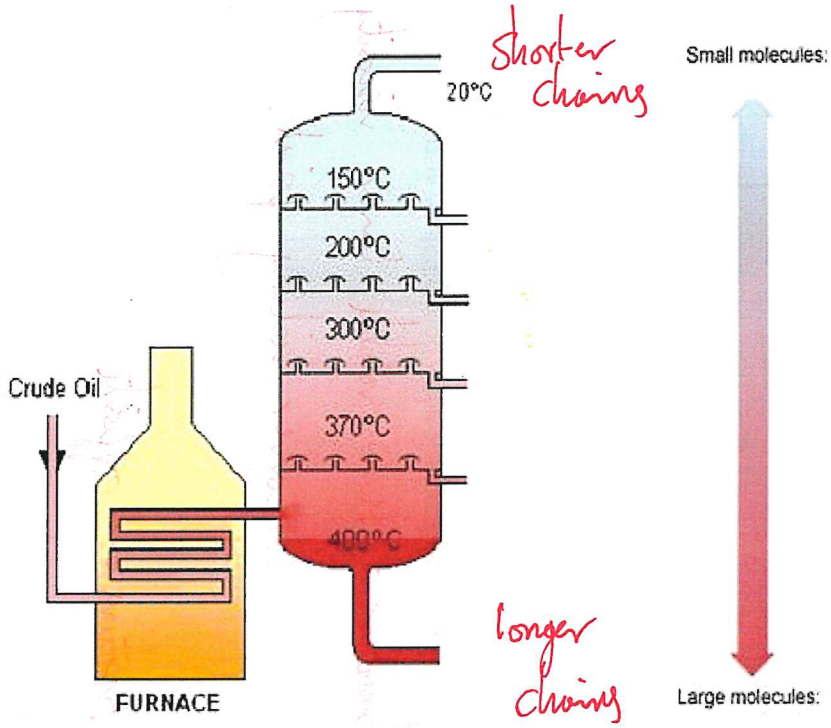
Larger alkanes have a larger Mr so have stronger intermolecular forces which require more energy and higher temperatures to overcome, hence they have higher boiling points.

Describe the variations between different fractions (colour/ boiling points/ viscosity)

Shorter chain/smaller = more volatile, lower viscosity, lighter colour fractions, lower boiling point.

longer chain fractions = opposite

Industrial fractional distillation of crude oil in an oil refinery



Fraction	Average chain length	Use
Refinery Gases	1-4	Bottled gas for cooking and heating
Gasoline	4-12	Fuel for cars
Kerosene	11-15	Fuel for aeroplanes
Diesel Oil	15-19	Fuel for lorries
Fuel Oil	30-40	Fuel for ships
Bitumen	50+	Road surfacing

1) Which fraction has the highest viscosity?

Bitumen

2) A hydrocarbon has the molecular formula $C_{17}H_{36}$, which fraction is this?

Diesel oil

3) Which fraction is the most volatile?

Refinery gases

4) Which fraction has the lightest colour?

Gasoline (Refinery gases)

5) Which fraction is used to fuel planes?

Kerosene

6) An alkane has 3 carbons in its chain. What might it be used for?

Cooking or heating

7) Describe how is crude oil separated into various fractions at the refinery?

① Crude oil is separated by fractional distillation

② Crude oil is heated and the oil evaporates

③ It enters the tower. As vapors rise, the temperature falls

④ Different sized fractions condense at different heights because they have different boiling points.

8) Suggest why we should try to conserve our reserves of crude oil?

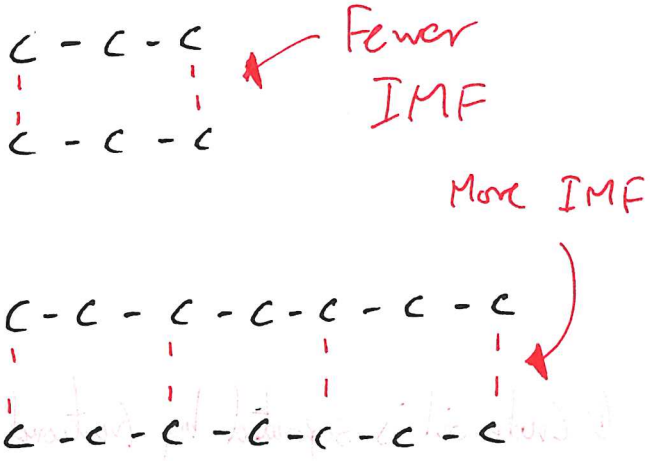
Crude oil is a finite, non-renewable energy resource

9) Describe the relationship between the average chain length of the fraction and the boiling point

As the chain length increases, the boiling point increases

10) Explain this trend. Draw a diagram to illustrate your answer.

- Longer chain length means more intermolecular forces between molecules.
- Requires more energy to overcome



Reactions of Alkanes

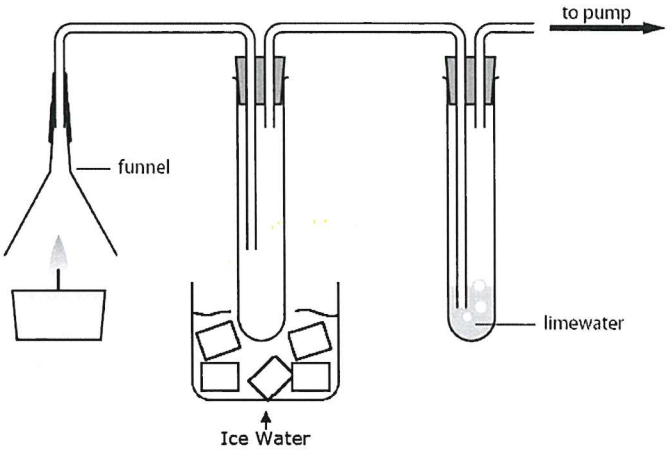
Learning Outcomes:

1) Define the term fuel
2) Recall the possible products of complete and incomplete combustion of hydrocarbons with oxygen in the air
3) Explain why carbon monoxide is poisonous
4) Describe a test for the presence of water

Key definition

A fuel is a substance that, when burned, releases heat energy. This is an exothermic process.

Reaction with oxygen (Combustion)



Method

The products of a burning a fuel, e.g. candle, are drawn through the apparatus by a pump.

1) Describe and explain what happens to the limewater? What does this tell us about what elements are in crude oil?

- The limewater will turn cloudy
- CO_2 is present
- Carbon is present in oil

2) The liquid forms in the first boiling tube. Describe a test to show that the liquid is water. What does this tell us about what elements are in crude oil?

- Water turns anhydrous copper sulfate from white to blue
- Hydrogen is present in crude oil

All alkanes burn in air. If there is enough oxygen in the air they burn completely to give carbon dioxide & water only. This is complete combustion.

fuel	+	**oxygen**	→	**carbon dioxide**	+	**water**
methane	+	oxygen	→	carbon dioxide	+	water
CH_4	+	$2O_2$	→	CO_2	+	$2H_2O$

Task: Now, write the word and the balanced symbol equations for the burning of ethane:

ethane + Oxygen → carbon dioxide + water

$C_2H_6 + 3\frac{1}{2} O_2 \rightarrow 2CO_2 + 3 H_2O$

O = 4 + 3 = 7

Task: *Write the <u>word</u> & <u>chemical</u> equations for the combustion of the next three alkanes*

<u>Propane</u>

Propane + Oxygen → Carbon dioxide + water

$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$

<u>Butane</u>

Butane + Oxygen → Carbon dioxide + water

$C_4H_{10} + 6\frac{1}{2}O_2 \rightarrow 4CO_2 + 5H_2O$

<u>Pentane:</u>

Pentane + Oxygen → Carbon dioxide + water

$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$

<u>Hexane:</u>

Hexane + Oxygen → carbon dioxide + water

$C_6H_{14} + 9\frac{1}{2}O_2 \rightarrow 6CO_2 + 7H_2O$

Incomplete combustion

If there isn't enough oxygen then carbon monoxide or carbon (soot) is produced. This is called incomplete combustion.

Carbon monoxide is dangerous:

- it is **toxic**
- because it reduces the capacity of the blood to carry oxygen

} 2 marks

Possible equations for incomplete combustion of ethane

$$C_2H_6 + 2\tfrac{1}{2}O_2 \rightarrow 2CO + 3H_2O$$

$$C_2H_6 + 1\tfrac{1}{2}O_2 \rightarrow 2C + 3H_2O$$

$$C_2H_6 + 2O_2 \rightarrow CO + C + 3H_2O$$

Task: How many different chemical equations can you write for the combustion of pentane?

$$C_5H_{12} + 5\tfrac{1}{2}O_2 \rightarrow 5CO + 6H_2O$$

$$C_5H_{12} + 3O_2 \rightarrow 5C + 6H_2O$$

$$C_5H_{12} + 5O_2 \rightarrow 4CO + C + 6H_2O$$

$$C_5H_{12} + 4\tfrac{1}{2}O_2 \rightarrow 3CO + 2C + 6H_2O$$

$$3CO + C + CO_2 + 6H_2O$$

Problems with burning fuels

Apart from any issues with incomplete combustion producing poisonous carbon monoxide, even the complete combustion of fuels has associated problems:

1) Burning fuels produces carbon dioxide:

Problem:

Increases levels of CO_2 in the atmosphere, contributes to climate change.

$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$

2) Car engines reach a very high temperature:

Problem:

The high temperature causes nitrogen and oxygen from the air to react forming oxides of nitrogen.

$N_2 + O_2 \rightarrow 2NO$

Nitrogen oxides can be converted to Nitric acid in the atmosphere + therefore contribute to acid rain.

3) Some fuels contain impurities such as sulfur which also burns when the fuel does:

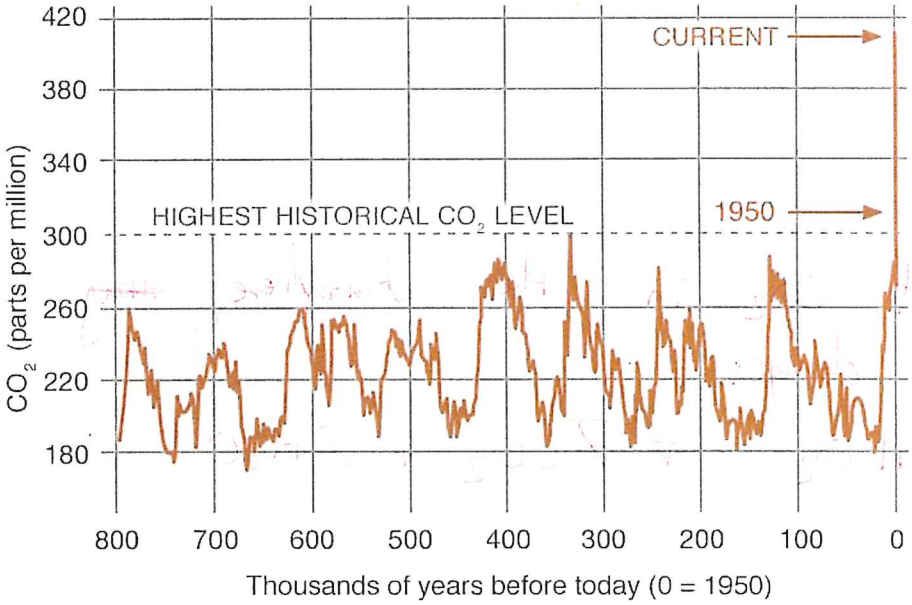
Problem:

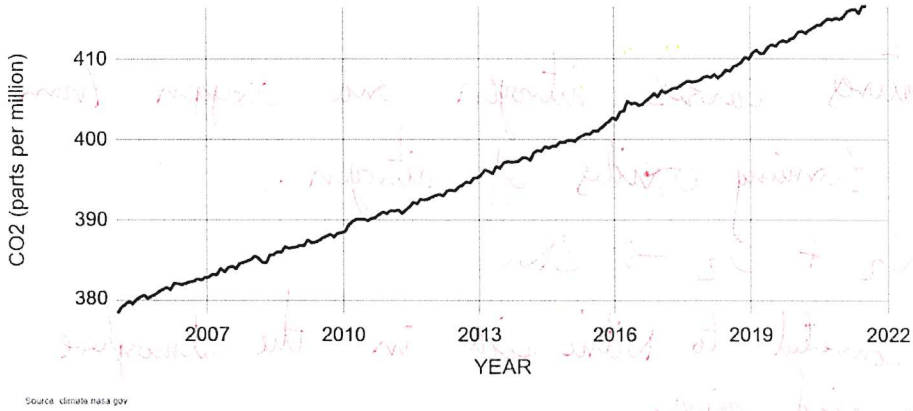
When fuels are burnt the Sulfur impurities react with Oxygen, producing Sulfur dioxide: $S + O_2 \rightarrow SO_2$. Sulfur dioxide reacts with water and Oxygen in the atmosphere forming Sulfuric acid: $2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4$.

This contributes to acid rain - kills trees and fish in lakes.

Just here for discussion!

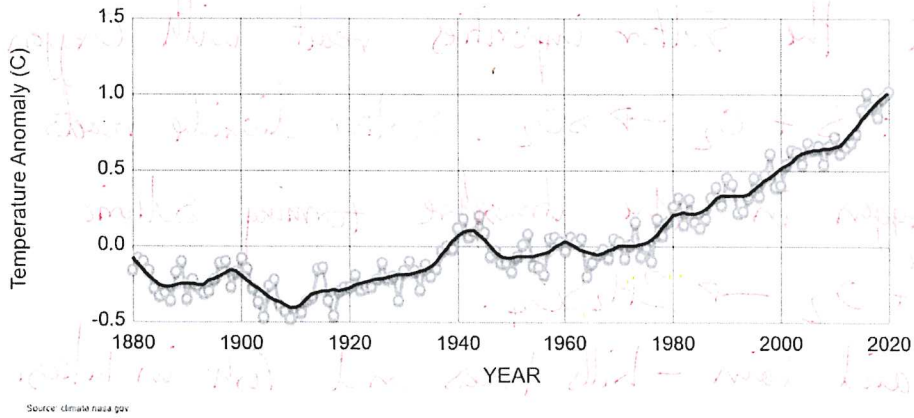
Problems with increasing atmospheric carbon dioxide levels:





Source: climate.nasa.gov

Change in average global temperature compared with 1951-1980



Source: climate.nasa.gov

Exam Style Questions

1 The following compounds are found in crude oil:

A C_3H_8

B C_8H_{18}

C $C_{12}H_{26}$

D $C_{16}H_{34}$

Which of these compounds:

(a) has the highest boiling point? ..$C_{16}H_{34}$..

(b) catches fire most easily? ..C_3H_8..

(c) is collected at the top of the fractional distillation column when crude oil is distilled? C_3H_8

(d) is the most viscous? ..$C_{16}H_{34}$.. (4)

2 Crude oil is a mixture of many different hydrocarbons.

Write these words into the spaces below: alkanes, compounds, fractions, molecules

(a) Crude oil is separated by distillation into ..fractions.. containing hydrocarbons with similar boiling points.

(b) Hydrocarbons with the smallest ..molecules.. have the lowest boiling points.

(c) Hydrocarbons are ..molecules (or compounds).. of hydrogen and carbon only.

(d) Crude oil contains ..mostly saturated alkanes.. . (4)

3 The table shows the number of carbon atoms in the molecules of four fuels obtained from crude oil.

Fuel	Number of carbon atoms in molecules
petroleum gases	2–4
petrol	4–10
kerosene	10–15
diesel oil	14–19

(a) The fuel with the highest boiling point is diesel oil (1)

(b) Petrol ...

A has a higher boiling point than diesel oil.

B is a thinner liquid than diesel oil.

C ignites less easily than kerosene.

D has larger molecules than kerosene. (1)

(c) The molecule C_4H_{10} could be in ...

A petrol only.

B petrol and kerosene.

C petrol and petroleum gases.

D petroleum gases only. (1)

(d) Which one of the following is a saturated hydrocarbon that could be in diesel oil?

A $C_{12}H_{26}$

B $C_{16}H_{32}$

C $C_{17}H_{36}$

D $C_{18}H_{38}O$ (1)

4 Pentane, C_5H_{12}, is a hydrocarbon fuel. It burns completely in plenty of air.

(a) Name the gas in the air that pentane reacts with when it burns.

Oxygen (1)

(b) Write a word equation for the combustion of pentane in plenty of air.

Pentane + Oxygen → Carbon dioxide + water (2)

(c) Write a chemical equation for this reaction.

$C_5H_{12} + 8O_2 \rightarrow 5CO_2 + 6H_2O$ (2)

(d) When the air supply is limited, the combustion is described as incomplete (1)

and a poisonous gas is produced. Name this gas.

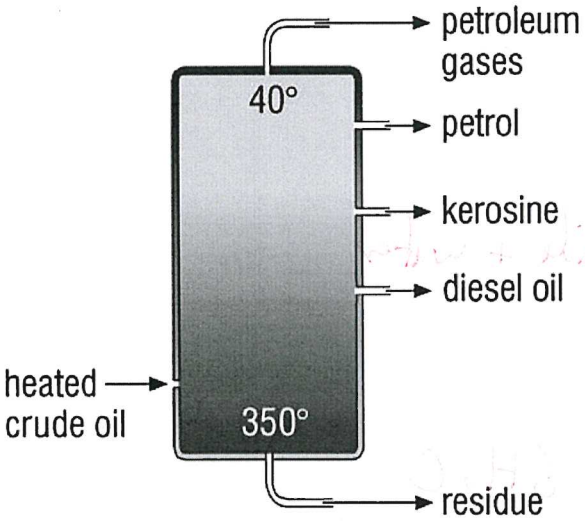
Carbon monoxide (1)

(e) Write a chemical equation for the combustion of pentane in a limited supply of air.

$C_5H_{12} + 5\frac{1}{2}O_2 \rightarrow 6H_2O + 3CO + CO_2 + C$ (2)

or any other correct combination of products.

5 Crude oil is separated by fractional distillation. In oil refineries this is done in tall towers called fractionating columns.



Give the main steps in this process and explain how the different fractions are separated in a fractionating column.

- Crude oil is heated until it becomes a gas
- Then passed into bottom of column
- Column is hotter at bottom and cooler at top
- Gases rise + each fraction is collected as it condenses at the height where temperature = boiling point of that fraction
- Fractions are collected seperately at each height.

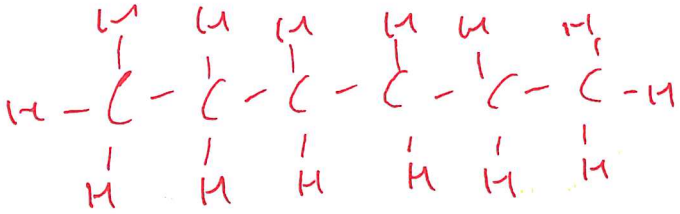
(4)

6 (a) Give the molecular formula for hexane

C_6H_{14}

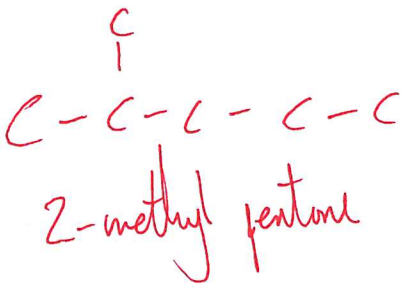
(1)

(b) Draw the displayed formula for hexane

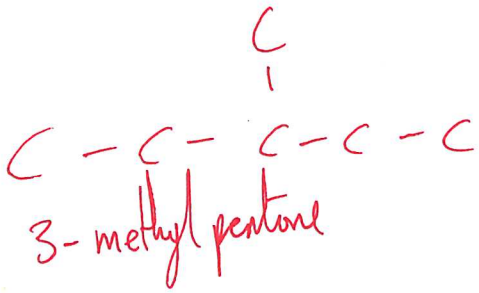


(2)

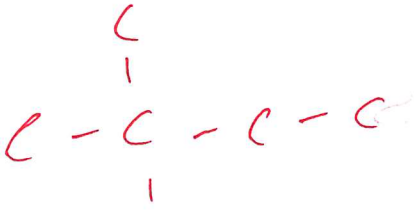
(c) Draw the displayed formula for 4 other isomers of C_6H_{14} (be careful: there are only 4; some you might try to draw are the same as others if you twist them around)



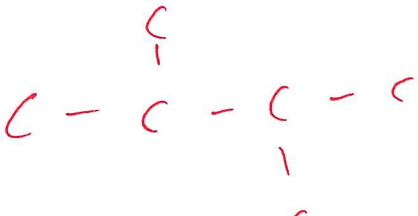
2-methyl pentane



3-methyl pentane



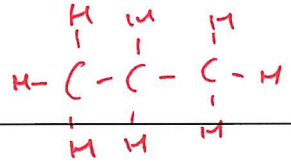
2,2-dimethylketone



2,3-dimethyl ketone

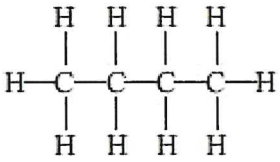
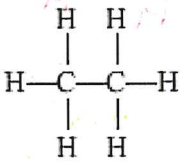
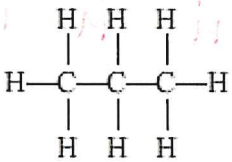
(8)

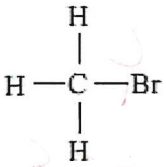
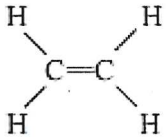
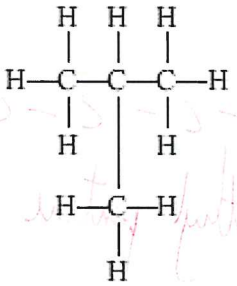
7 (a) Draw the displayed formula of an alkane containing 3 carbon atoms, and give its name



Propane (3)

These are the displayed formulae of 6 organic compounds:

		
P	**Q**	**R**

		
S	**T**	**U**

(b) Use the letter above to select

(i) the compound which is **not** a hydrocarbon S (1)

(ii) the compound which is a hydrocarbon but not an alkane T (1)

(iii) the 2 compounds which are isomers of each other P + U (2)

(c) Explain what isomers are

- Molecules with the same molecular formula
- But different displayed formula

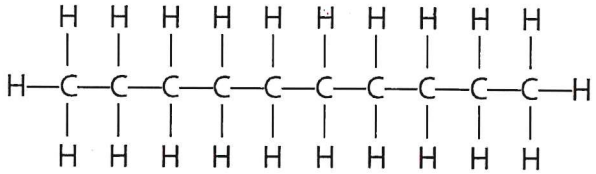
(2)

(d) What is the general formula of the alkanes?

C_nH_{2n+2} (1)

8 Decane is a hydrocarbon found in crude oil.

The diagram below shows the structure of a molecule of decane.



(a) Explain why decane is described as a hydrocarbon

It is a molecule containing Carbon + Hydrogen ONLY (2)

(b) Give the molecular formula for decane $C_{10}H_{22}$ (1)