Fractional distillation and petrochemicals

4.7.1.2 · Organic chemistry · revision notes

How crude oil is separated into fractions by fractional distillation, and how the fractions are used as fuels and as feedstock for the petrochemical industry. Expect labelled diagrams of the column, 'explain how fractional distillation works' questions (often 4 to 6 marks) and questions on uses.

Key facts

- Fraction = mixture of hydrocarbons with similar numbers of carbon atoms (similar boiling points)
- Evaporate, rise, then condense where the temperature is below the boiling point
- Large molecules: high boiling points, collected at the bottom
- Petrochemical products: solvents, lubricants, polymers, detergents
- Column: hot at the bottom, cool at the top
- Small molecules: low boiling points, collected at the top
- Fuels: LPG, petrol, kerosene, diesel oil, heavy fuel oil
- Feedstock = raw material used to make other chemicals

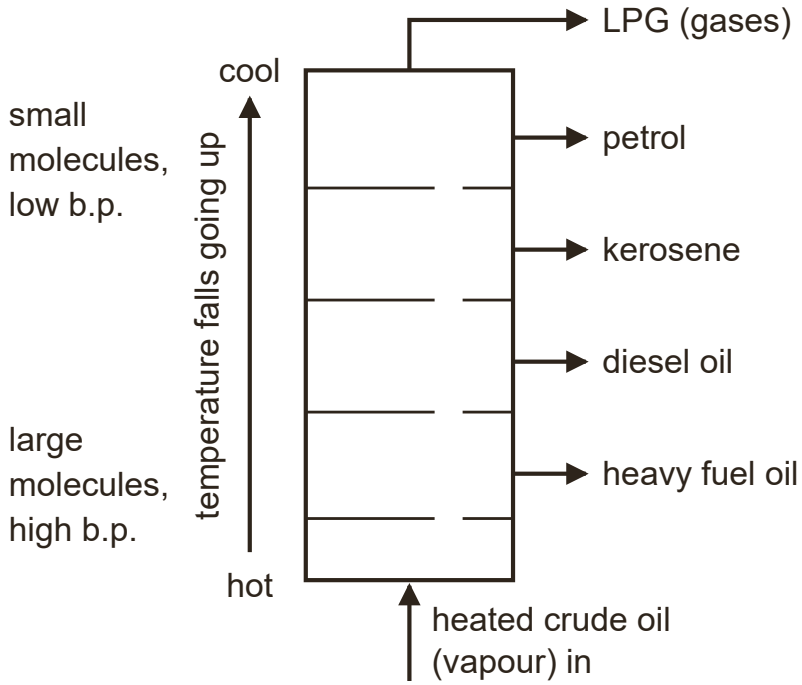
Notes

Fractional distillation

- The hydrocarbons in crude oil have different boiling points, mainly because their molecules are different sizes.
- **Fractional distillation** separates crude oil into **fractions**. Each fraction is a mixture of hydrocarbons with a **similar number of carbon atoms**, so they have similar boiling points.
- 1. The crude oil is heated until most of it **evaporates** (turns into vapour).
- 2. The vapour goes into the bottom of a **fractionating column**, which is **hot at the bottom and cooler towards the top**.
- 3. The vapours rise up the column. Each hydrocarbon **condenses** (turns back into a liquid) when it reaches a level where the temperature is **below its boiling point**.
- 4. The liquids are collected at different heights. Hydrocarbons with very low boiling points stay as gases and leave at the top; those with the highest boiling points are collected at the bottom.
- It is a physical process: the molecules are separated, but none of them are broken up.

Where each fraction comes out

- Near the top (cooler): small molecules with low boiling points. LPG leaves the very top as a gas; petrol condenses just below.
- Lower down (hotter): larger molecules with higher boiling points, such as diesel oil and heavy fuel oil.
- Order from top to bottom: LPG, petrol, kerosene, diesel oil, heavy fuel oil.



Each hydrocarbon condenses at the level where the temperature is just below its boiling point.

- Going down the column, the molecules get bigger and the boiling points get higher.

Fuels and feedstock

- The fractions are processed to make **fuels** and **feedstock** (raw materials) for the **petrochemical industry**.
- Many fuels that modern life depends on come from crude oil: petrol (cars), diesel oil (cars, lorries and trains), kerosene (aircraft), heavy fuel oil (ships and power stations) and LPG (heating and cooking).
- The petrochemical industry makes many useful materials: **solvents, lubricants, polymers and detergents**.
- There is a vast range of natural and synthetic carbon compounds because carbon atoms can form **families of similar compounds**: carbon atoms bond to each other to make chains (and rings) of many different lengths.

How to answer each type of question

Recall: fuels and petrochemical products

1 to 2 marks | Grade 3

1. Use the names in the specification: petrol, diesel oil, kerosene, heavy fuel oil, LPG.
2. For petrochemical products, choose from solvents, lubricants, polymers and detergents.
3. Give only as many answers as the question asks for.

Example. Give **two** useful materials, other than fuels, that are made by the petrochemical industry.

Model answer. Any two from: solvents (1), lubricants (1), polymers (1), detergents (1). Maximum 2 marks.

Explain how fractional distillation separates crude oil

3 to 6 marks | Grade 5

1. Start with heating: the crude oil evaporates.
2. Describe the column: hot at the bottom, cooler at the top.
3. The vapours rise and each hydrocarbon condenses when the temperature falls below its boiling point.
4. Link size to position: large molecules (high boiling points) condense low down; small molecules condense near the top or leave as gases.
5. Use the words 'evaporate' and 'condense': examiners look for both.

Example. Explain how crude oil is separated into fractions in a fractionating column. (4 marks)

Model answer. The crude oil is heated so that it evaporates (1). The column is hot at the bottom and cooler at the top (1). The vapours rise, and each hydrocarbon condenses when it reaches a level where the temperature is below its boiling point (1). Hydrocarbons with larger molecules have higher boiling points, so they condense lower down; small molecules condense near the top or leave as gases (1).

Use data to place a fraction or a hydrocarbon

1 to 2 marks | Grade 5

1. Read the boiling range or the number of carbon atoms from the table.
2. A higher boiling point means lower down the column, where it is hotter.
3. Match a given boiling point to the range it falls inside.

Example. The table shows the boiling ranges of three fractions.

Fraction	Boiling range in °C
X	40 to 180
Y	180 to 260
Z	260 to 350

(a) Which fraction is collected highest up the column? Give a reason.
(b) A hydrocarbon boils at 230 °C. Which fraction is it in?

Model answer.

(a) X (1). It has the lowest boiling points, and the top of the column is the coolest part (1).
(b) Y (1)

Explain why there are so many carbon compounds

2 marks | Grade 7

1. Say that carbon atoms can form bonds with other carbon atoms.
2. Say that this makes chains (or rings) of different lengths, giving families of similar compounds.

Example. There are millions of different carbon compounds, both natural and synthetic. Explain why.

Model answer. Carbon atoms can form covalent bonds with other carbon atoms (1), so they make chains or rings of many different lengths, forming families of similar compounds (1).

Don’t lose marks

- Saying the column is hottest at the top. It is hottest at the bottom, where the hot vapour enters.
- Saying fractions 'evaporate at different heights'. They condense at different heights.
- Saying fractional distillation breaks molecules into smaller ones. It only separates them; breaking molecules is cracking.
- Calling a fraction a pure substance. Each fraction is still a mixture of hydrocarbons.

More tips

Memory tricks

- Hot at the bottom, cool at the top: small molecules make it to the top before they condense.
- Fuels from top to bottom: 'Lazy Pupils Keep Doing Homework' = LPG, petrol, kerosene, diesel oil, heavy fuel oil.
- Evaporate on the way in, condense on the way out. Every explanation needs both words.
- Size, boiling point, height: bigger molecule, higher boiling point, lower down the column.

Exam technique

- In 6-mark questions, describe the process in order: heat, evaporate, enter the column, temperature gradient, rise, condense, collect. A logical sequence is part of the level.
- Link three things for full marks: molecule size, boiling point and height in the column.
- If the diagram labels the fractions with letters, refer to those letters in your answer.
- Learn one use for each fuel. 'Used as a fuel' on its own rarely scores.

What each grade needs

What you need to be able to do, from the first marks up to the top grade.

Grade 3 — **Name fuels produced from crude oil**
Petrol, diesel oil, kerosene, heavy fuel oil and liquefied petroleum gases (LPG).

Grade 3 — **Name materials made by the petrochemical industry**
Solvents, lubricants, polymers and detergents.

Grade 4 — **Define a fraction**
A mixture of hydrocarbons with a similar number of carbon atoms, and so similar boiling points.

Grade 5 — **Describe the temperature gradient in the column**
The fractionating column is hottest at the bottom and coolest at the top.

Grade 5 — **Explain what feedstock means**
A raw material used to make other chemicals; fractions are feedstock for the petrochemical industry.

Grade 5 — **Explain fractional distillation using evaporation and condensation**
Crude oil is evaporated; the vapours rise and each hydrocarbon condenses where the temperature falls below its boiling point.

Grade 7 — **Explain why there are so many carbon compounds**
Carbon atoms can bond to each other to form chains of different lengths, making families of similar compounds.

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