Research
Based
Curricula

MAKE
HAPPEN

Improving Water Purification with 2D Materials

Key Stage 5

Chemistry

2021

BROUGHT TO YOU BY RBC ACCESS ED

Contents

Part 1: Introduction

Part 2: Resources

Each resource is a chapter with activities to complete to demonstrate learning

Part 3: Tips and Guidance

For Students
Getting Started

RBC means Research-Based Curriculum,. Each RBC coursebook is written by a PhD student at a university about their cutting edge research.

Why complete an independent 'RBC' study pack?

RBC courses are challenge courses to sharpen your skills and resilience: finishing an RBC course is a major accomplishment to add to your academic CV. To get into a university, you must demonstrate that you are intellectually curious, and will make the most of the academic opportunities available to you. Completing a pack will allow you to gain invaluable experience to write about in your university application..

It allows you to:

- ✓ Build your subject experience to mention in your UCAS Personal Statement
- ✓ Sharpen your academic skills
- ✓ Experience what it's like to study beyond school and at university
- ✓ Better understand what you enjoy and don't enjoy
- ✓ Improve your overall subject understanding ahead of final exams

For Students
Getting Started

What's in this booklet?

Your RBC booklet is a pack of resources containing:

- ✓ More about how and why study this subject
- ✓ Six 'resources' each as a lesson with activities
- ✓ A final assignment to gauge learning
- ✓ Extra guidance throughout about the university skills you are building
- ✓ End notes on extra resources and where to find more information

Who should complete this pack?

Anyone interested in improving their academic skills or understanding what they should do at university. This pack is especially suitable for anyone interested in studying Science.

Even if you are unsure of where your interest in this subject can take you, by completing this pack you will have a clearer idea of the variety of subjects that link to one another.

If you have any questions while you are using the resources in this pack, you can contact your teacher or email us directly at schools@access-ed.ngo.

Good luck with your journey to higher education!

For Students
University Skills

Look out for these Key **Skills Badges throughout the coursebook.** These show that you're building the learning skills you'll need to succeed at University and in Higher Education.

To complete this resource, you will have to demonstrate impressive academic skills. When universities are looking for new students, they will want young people who can study independently and go above and beyond the curriculum. All these skills that you will see here will demonstrate your abilities as a university student – while you're still at school!

Every time you have to look something up or write up a reference, you are showing that you can work independently.

Every time you complete a challenging problem or write an answer to a difficult question, you might demonstrate your ability to think logically or build an argument.

Every time you evaluate the sources or data that you are presented with, you are showing that you can 'dive deep' into an unfamiliar topic and learn from it!

Skills you will build for university:

independent research	your ability to work on your own and find answers online or in books
creativity	your ability to create something original and express your ideas
problem solving	your ability to apply what you know to new problems
building an argument	your ability to logically express yourself
providing evidence	your ability to refer to sources that back up your opinions/ideas
academic referencing	your ability to refer to what others have said in your answer, and credit them for their ideas
deep dive	your ability to go above and beyond the school curriculum to new areas of knowledge
source analysis	your ability to evaluate sources (e.g. for bias, origin, purpose)
data interpretation	your ability to discuss the implications of what the numbers show
active reading	your ability to engage with what you are reading by highlighting and annotating
critical thinking	Your ability to consider questions with an open mind and evaluate what is important or not

Where can this subject take me?

Pathways

Studying Biology or Psychology can open the doors to many degrees and careers. It intersects with Microbiology, Chemistry, Physiology and Sociology. Whatever interests you is likely to relate to Biology in some way. See a snapshot of where studying Biology and Psychology can take you.

Transferrable skills' from Chemistry to a career:

- strong mathematical/numerical ability,
- analysis and problem solving time management and organisation
- written and oral communication
- monitoring/maintaining records and data
- teamwork
- research and presentation

What are some are the 'interdisciplinary' subjects in this course?

Interdisciplinary is a term you will hear used by higher education institutions. It's also how many professionals and academics in the real world operate: they use multiple subjects, or disciplines, to carry out their work.

Thinking about which subjects you like, alongside Maths, can help you choose a career pathway later.

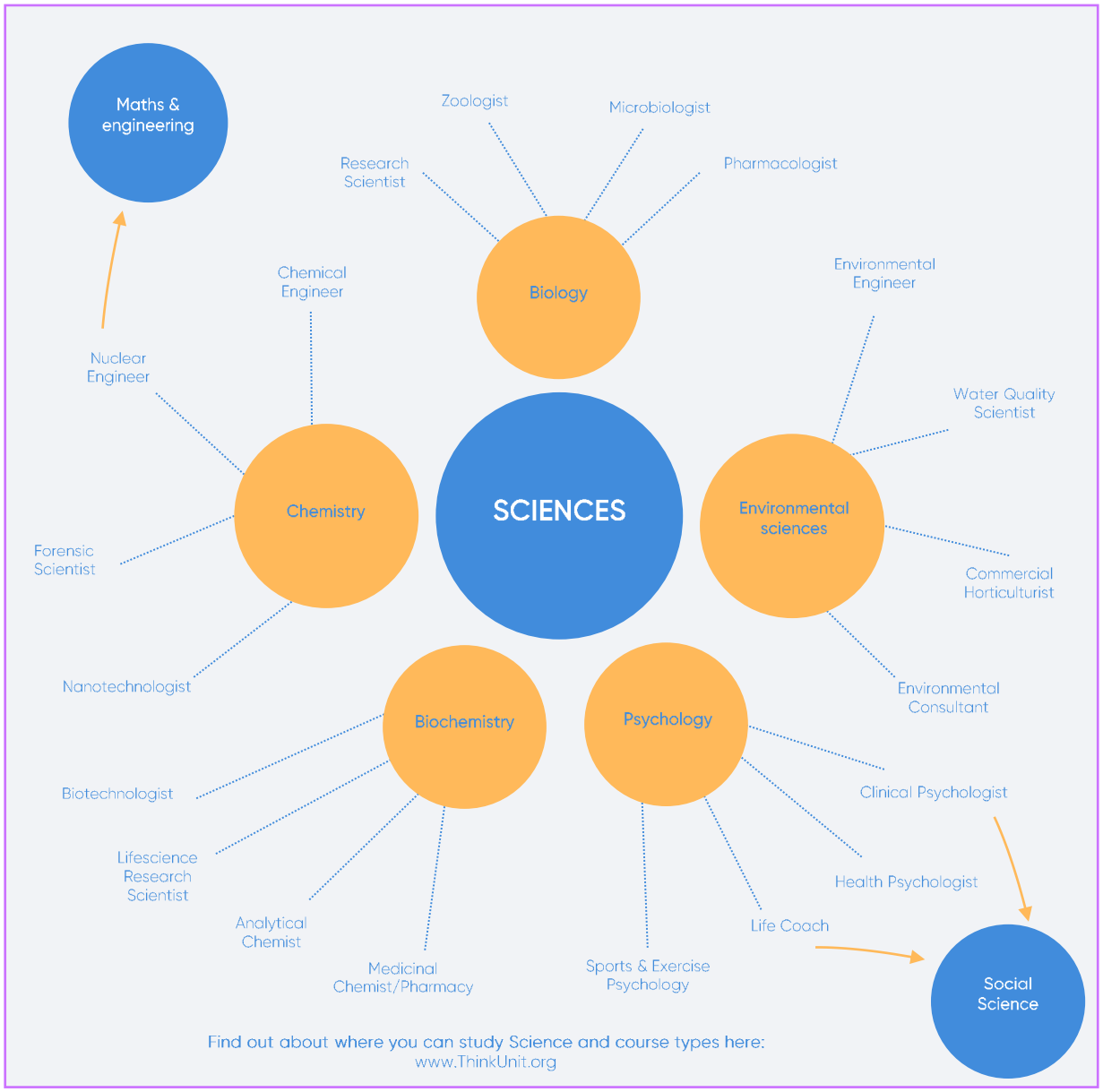
Read more about subject selection and careers pathways:

https://targetjobs.co.uk
https://www.prospects.ac.uk
https://thinkuni.org/

Subject map: Sciences

A degree in Sciences gives Students access to a large number of career choices. Many students who study Sciences go on to pursue their Master's degree in Science. However, a significant proportion of them also start looking out for jobs in the field of Cancer research, Stem Cell technology and other positions in this space.

Did you know? Being a scientist can open up many doors within many industries, from managing projects to working in a lab and with health policy teams in governments!



Find our about Science-related careers here:
PROSPECTS: https://www.prospects.ac.uk
TARGET JOBS: https://targetjobs.co.uk

For Teachers
RBC Guide

Learner aims

The Research-Based Curriculum aims to support student attainment and university progression by providing classroom resources about cutting-edge research at local universities. The resources are designed to:

- ✓ promote intellectual curiosity through exposure to academic research
- ✓ stretch and challenge students to think deeply about content that may be beyond the confines of the curriculum
- ✓ develop core academic skills, including critical thinking, metacognition, and written and verbal communication
- ✓ inform students about how subjects are studied at university, and provide information, advice and guidance on pursuing subjects at undergraduate level

Content

The programme represents a unique collaboration between universities and schools. Trained by AccessEd, PhD Researchers use their subject expertise to create rich resources that help bring new discoveries and debates to students.

The Research-Based Curriculum offers twelve modules suitable for either KS4 or KS5 study. The modules span a range of disciplines, including EBacc and A-level subjects, as well as degree subjects like Biochemistry. Each module includes six hours of teaching content, supported by student packs, teacher notes and slides. All modules are available online and free of charge for teachers at select schools.

Using the RBC pack

These resources are designed to be used flexibly by teachers. The resources can be completed by students individually or in groups, in or out of the classroom.

For Teachers
Using the RBC packs

Here are five examples of delivery options:

Extra-Curricular Subject Enrichment Clubs

The resources can be completed in small groups (4-8 pupils) across a series of weekly lunch clubs or after-school clubs online or in person. Groups can reflect on their learning by presenting a talk or poster on the subject matter at the end of the course.

The resources can be used by students to explore subjects that they are interested in studying at university. This can inform their decision making with regards to university degree courses and allow students to write more effective Personal Statements by including reflections on the Research-Based Curriculum.

The resources can be used to ignite curiosity in new topics and encourage independent research. Schools could hold a research challenge across a class or year group to submit a piece of work based on the resources. Pupils could submit individually or in small groups, with a final celebration event.

Resource packs can function as 'transition' projects over the summer, serving as an introduction to the next level of study between KS3 and KS4, or KS4 and KS5. Students could present their reflections on the experience in a journal.

The Research-Based Curricula programme builds on the University Learning in Schools programme (ULiS), which was successfully delivered and evaluated through the London Schools Excellence Fund in 2015. The project was designed in a collaboration between Achievement for All and The Brilliant Club, the latter being the sister organisation of AccessEd. ULiS resulted in the design and dissemination of 15 Schemes of Work based on PhD research for teachers and pupils at Key Stage 3. The project was evaluated by LKMCo. Overall, pupils made higher than expected progress and felt more engaged with the subject content. The full evaluation can be found here: ULiS Evaluation.

Questions

For more information contact hello@access-ed.ngo

Introduction to Topic Inorganic, Organic and Polymer Chemistry's

The end goal of this pack is for you to understand how organic, inorganic and **polymer** chemistry's and environmental science all tie together to improve water purification.

The topics within this pack will include:

- An introduction to **metal-organic materials**
- Why 2D is better!
- Characterisation techniques for inorganic materials
- The basics of **polymers**
- **Membranes:** what are they and why do we need them?
- The importance of water purification

In my research, I combine all of these disciplines to solve real world problems. We take drinking water for granted, good filtrations systems and treatment plants means that in the UK, we have access to clean water all year. Straight out of the tap. However in some countries this is not the case. Diseases from drinking dirty and contaminated water is commonplace.

Also, due to the ever growing industrialisation of the planet, more and more water is being used for industrial processes and then being discarded as polluted waste water. This is a big environmental challenge, pollutants in water get into our ecosystems and affect the planet in ways we don't yet understand.

One of the easiest ways to clean contaminated and polluted water is using filtration. This is passing water through a **membrane** that blocks the **contaminants** and lets the water pass through. Most **membranes** are **polymers**, so understanding the basics of **polymer** science is key here. However these **polymer** membranes have a big trade off between how fast the water flows through and how much of the **contaminants** it rejects. A new way to improve this trade off in **polymer** membranes is by adding filler compounds. These filler compounds can be either organic molecules, inorganic compounds or a mixture of the two. Materials that are a mixture of organic and inorganic that we will be exploring in this coursebook are called **metal-organic materials**.

In this course book we will explore what **metal-organic materials** are, tying in both organic and inorganic chemistry. We will also look at **polymers** and how they can be used as membranes for effective water filtration. Lastly we will tie all of the chemistry together with the environmental science aspect in looking at why we need water purification technologies, why it is important for both the environment and helping developing countries.

Introduction to Topic Chemistry

Studying chemistry at university is different from A-Level chemistry in so many ways. You are able to explore concepts and ideas introduced to you in school in much greater depth, understanding the fundamentals of how the planet works. When you get to university, chemistry gets split into 3 areas; organic, inorganic and physical chemistry. You have already learnt topics from these areas at school without realising, but at university you get to go much deeper. Area's of biology, physics, engineering and maths all get pulled into chemistry as they all influence each other in the real world. After a year or two (depending on your specific university course) you are able to choose the modules you want to study and really focus on the areas that interest you.

A huge aspect of studying chemistry at university is the lab time. Most chemistry courses have weekly lab time, where you carry out experiments from the different areas of chemistry and learn lab skills that will take you forward in your degree and career. Most course also include at least one research project, where the chemistry is in your (supervised) hands. You get to decide what you're researching and how your will design the experiments. Personally this was one of my favourite parts about the undergraduate degree and really helped in my decision to do a PhD.

You learn so many transferrable skills in chemistry; data analysis, team work, project planning, time management, scientific and report writing, the list goes on – that chemists are some of the most employable graduates. You can choose to take your degree into industry, and continue using your lab skills and researching. Or you can take all of your highly transferrable skills and move into another area of work. I know chemistry graduates who have continued lab working, gone into accounting and banking, become a charity working, become a marketer – the options are endless. Studying chemistry is by no means easy, but the hard work and skills you learn stay with you for life.

Meet the PhD Researcher Freya Cleasby

In high school, during humanities lessons, I just couldn't quite get on board with the fact there was no "right answer". In Science and Maths there was always a right answer and I loved figuring that out. When choosing my GCSE subjects my dad laid out a career plan, ending with my dream job. He told me to work backwards – bit intense at 14 years old, I know! He asked me to pick 3 dream jobs but, in the end, I could only think of one – a research chemist.

After that I was on a straight path to becoming a research chemist at a big industrial company like GSK or Unilever. I chose to study Chemistry with a year in industry at the University of Sheffield, so that I could get a year head start on industry experience. After several rejections I finally got a placement at Croda, an industrial chemical supplier. I spent my year in their personal care team, making formulations and new sunscreen active ingredients. I absolutely loved working at Croda, however, I found that the scientific knowledge required was minimal; as long as the product worked the actual chemistry behind it was not important. I craved a more in-depth understanding of the science of what I was doing.

When going back to university for the 4th year of my degree I had to choose what my research project would be. After hearing that the organic chemistry groups often worked late into the night and at weekends, I quickly crossed those off in favour of a better work-life balance. I ended up picking an inorganic chemistry project, working on 3D **metal-organic frameworks**. I loved figuring out what was going on in my crystals and I ended up really getting the in-depth research I was missing in industry.

Meet the PhD Researcher Freya Cleasby

After my experience in my final year, I knew I wasn't quite ready to go into industry just yet. This led me to my current PhD project, still at the University of Sheffield, in 2D **metal-organic nanosheets** and using them for water purification. It was really important to me to have a real-world application for my project so that it felt like I was actually using chemistry for good (rather than evil!).

A-Level Subjects	Chemistry, Physics, Maths, Politics
Undergraduate	Chemistry (Integrated Masters with a Year in Industry)

Glossary

Term	Definition
Organic ligand	An organic molecule that is able to form coordination bonds from 2 or more functional groups on the molecule
Metal centre	A metal cation (positively charged ion) able to accept coordination bonds with organic ligands
Metal-organic material	An extended structure consisting of organic ligands and metal centres connected by coordination bonds
Metal-organic nanosheet (MON)	2D extended structures consisting of organic ligands and metal centres connected by coordination bonds
Metal-organic framework (MOF)	3D extended structures consisting of organic ligands and metal centres connected by coordination bonds
Coordination bond	A bond between an organic ligand and metal centre, where a ligand formally donates a lone pair of electrons to a metal cation
Tunable	The ability to selectively change the composition of metal-organic materials to suit a specific application
2D material / nanosheets	Crystalline solids consisting of a single layer of atoms
Top-down synthesis	Using an energetic process on a layered crystalline material to peel the layers apart into free-standing nanosheets
Bottom-up synthesis	Combining reagents in a chemical reaction to form free-standing nanosheets
NMR spectroscopy	Nuclear magnetic resonance spectroscopy. A spectroscopic technique, mainly for analysing organic components
IR spectroscopy	Infrared spectroscopy. A spectroscopic technique that uses infrared radiation to analyse organic compounds

Glossary

Term	Definition
XRD	X-ray diffraction. A method of analysing the structures of crystalline materials that uses X-ray radiation
Polymer	A material made up of large molecules composed of repeating building blocks
Monomer	Molecules that, when added together, make up polymers
Polymerisation	The synthesis of polymers
Membrane	A selective barrier
Flux	The measure of the flux of a substance through a membrane
Selectivity	The measure of how well membrane reject contaminants
Desalination	The removal of salt from water
Mixed matrix membranes (MMMs)	Inorganic fillers dispersed in a polymer
Spectroscopy	Use of the absorption and emission of light and other radiation by matter to study the structures of chemical compounds
Contaminant	A polluting substance that makes something impure. For example pharmaceutical waste in water
Exfoliation	Applying an energetic process to peel apart layers in a 3D layered materials to form free-standing 2D nanosheets

Resource One Overview

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Topic Metal-organic materials: the best of both worlds!

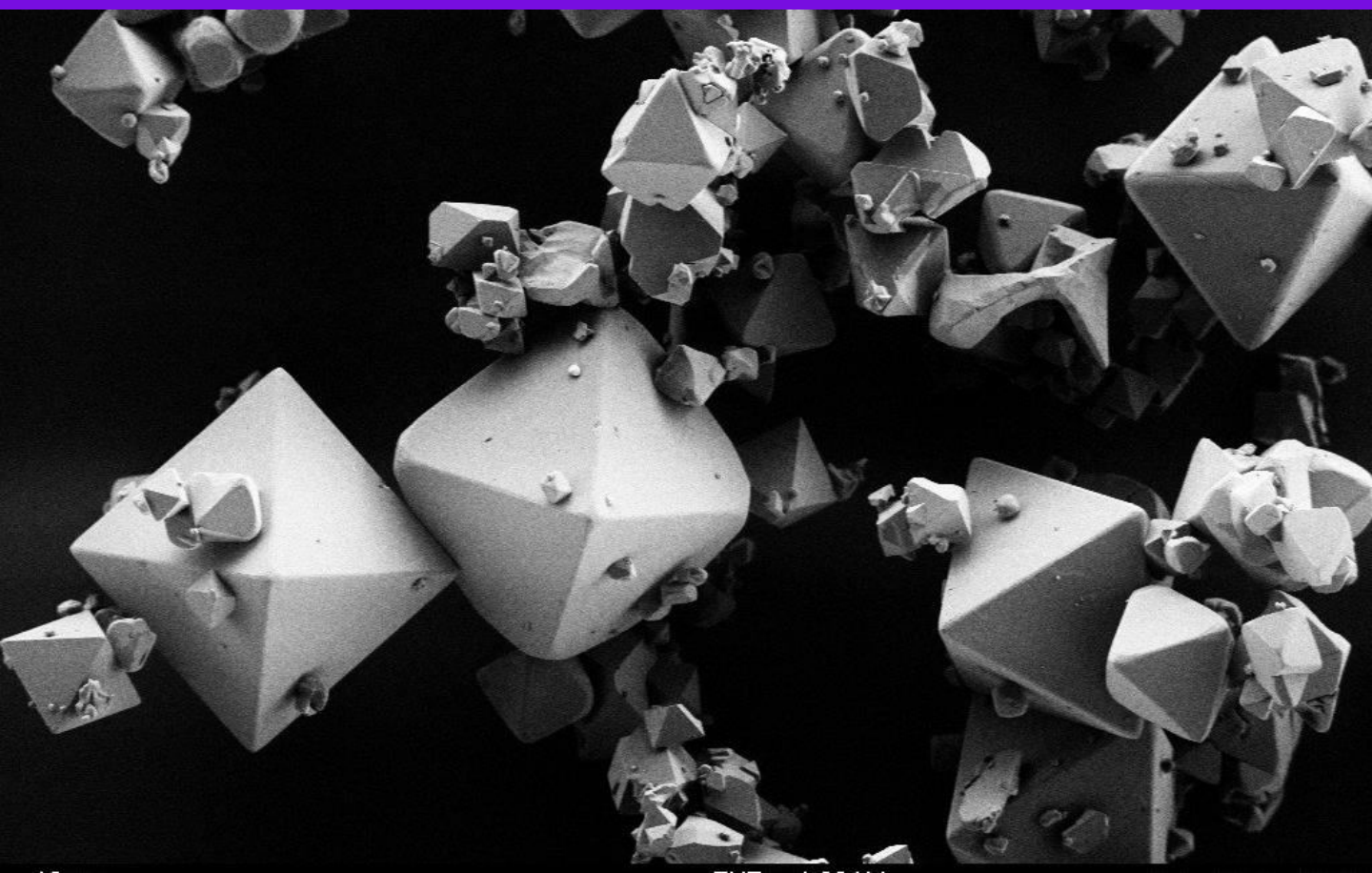
A-level Modules Bonding, Transition Metals, Carboxylic Acids, Amines, Organic Synthesis

Objectives By the end of this resource, you will be able to:

- ✓ Understand what an **organic ligand**, metal-node, **coordination bond** and pores are in the context of a **metal-organic frameworks** (MOFs)
- ✓ Describe the synthesis of common MOFs
- ✓ Explain why the structure of MOFs gives rise to different properties and how this can be used in different applications

Instructions

1. Read the data source
2. Complete the activities
3. Explore the further reading



Resource One
Data Source

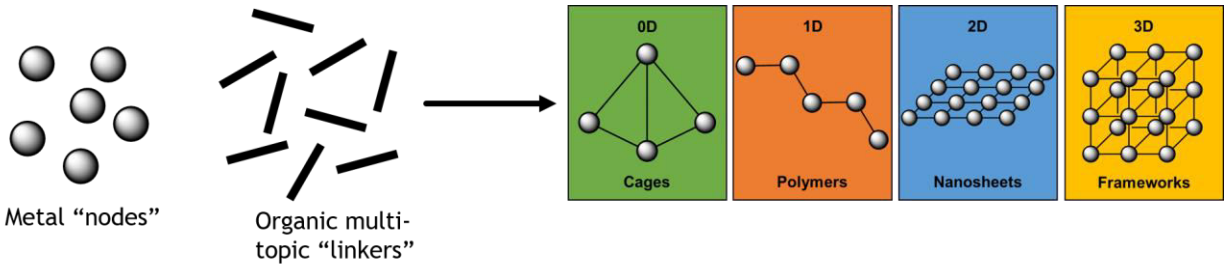
Section A

The building blocks of **metal-organic materials**

The basics of a **metal-organic material** can be broken down into two things; **organic ligands** and **metal centres**. These two building blocks are linked together by a type of bond called a **coordination bond** (we'll revisit these in section B). When **metal centres** and **organic ligands** come together in a node-and-linker type arrangement, 4 different structure types can form; 0-dimensional cages, 1-dimensional coordination polymers, 2-dimensional sheets and 3-dimensional frameworks.

Figure 1

Schematic depicting metal "nodes" and organic multi-topic "linkers" forming **metal-organic materials**

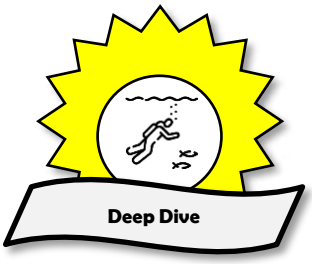


For the remainder of this chapter we will mostly focus on 3D metal organic frameworks (MOFs), however the same chemistry applies to all of the different structure types.

Resource One
Data Source

Section A

The building blocks of metal-organic materials

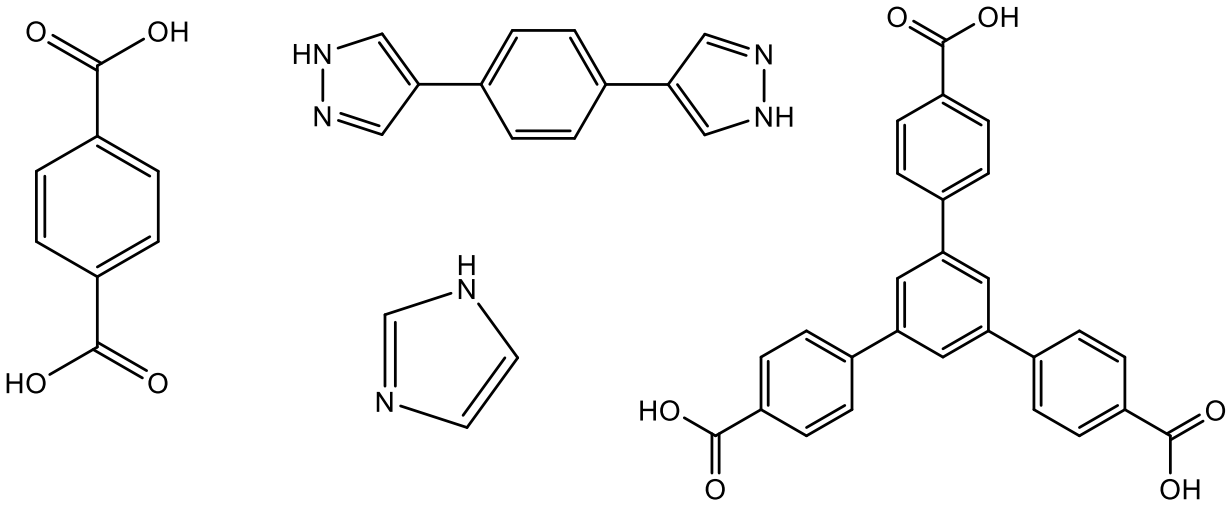


In order for the MOF to form a large complex structure, rather than a small molecule such as CH_4 or $CHCl_3$, the **organic ligands** must be able to form **coordination bonds** with more than one metal node. In order for the organic linkers to do this they must have more than one functional group within the structure that is able to form a **coordination bond** with the **metal centre**. When an organic molecule has only one functional group able to form a **coordination bond**, it is called *monotopic*. Organic molecules with more than one functional group are called *multitopic*.

Figure 2

Examples of **organic ligands** used in **metal-organic materials**

Common functional groups used for MOF ligands are carboxylic acids and amines (primary and secondary). Normally a ligand would have 2, 3 or 4 of the same coordinating functional group within its structure. Ligands often have aromatic rings within their structure.

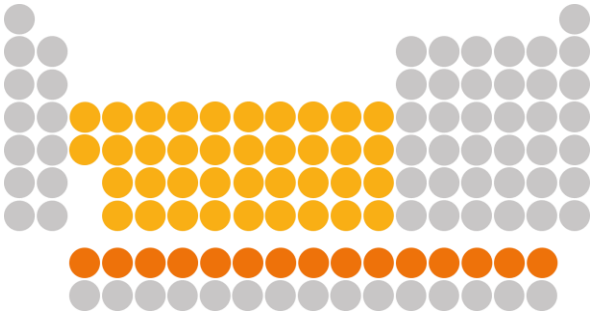


Resource One Data Source

Normally, the metal nodes in **metal-organic materials** are transition metals. However, lanthanides can also form **coordination bonds** and so they can also be used in **metal-organic materials**.

Figure 3

Periodic table graphic, transition metals in yellow, lanthanides in orange



Section B

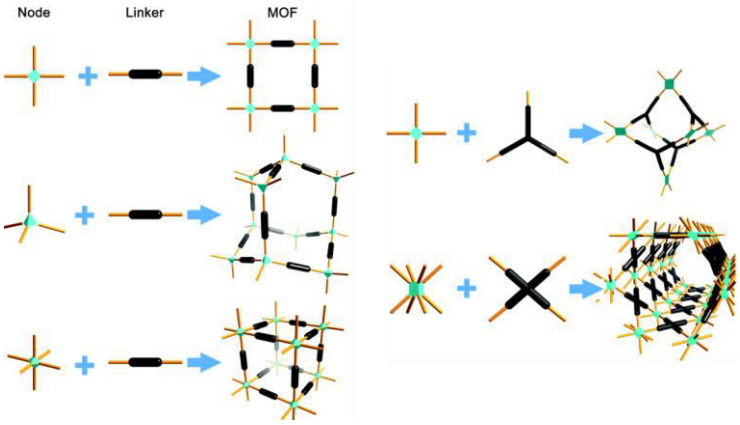
Structure and bonding in **metal-organic materials**

In MOFs, ligands and metals connect via **coordination bonds**. A **coordination bond** is where a ligand formally donates a lone pair of electrons to a metal cation. The number of **coordination bonds** a metal cation can accept is called the coordination number. Transition metals have coordination numbers between 2-9, with 6 being the most common.

The structure of the MOF strongly depends on the coordination number of the **metal centre**. The structure also depends on whether the ligand is flexible or rigid. In two and three dimensional structures; **metal-organic nanosheets** (MONs) and **metal-organic frameworks** (MOFs), holes or pores form within the structures. These pores can be tuned by changing the ligand length or functionality, which, in turn, can tune the MOF or MON for different applications.

Figure 4

Metal-organic material structures



Resource One
Data Source

The structure, functional groups and pore size can all be selectively tuned by selecting the right combination of ligand and metal. All these changes will impact the properties of the materials.

Section C

Synthesis of metal-organic materials

The most common form of synthesis (a chemical reaction to produce a compound) for MOFs is called solvothermal synthesis. This synthesis method involves dissolving ligands and metal salts in a solvent, heating the mixture past the boiling point of the solvent so that the reaction occurs in the vapour phase. The reaction is then cooled very slowly so that large crystals form as they come out of both the vapour phase and the solution.

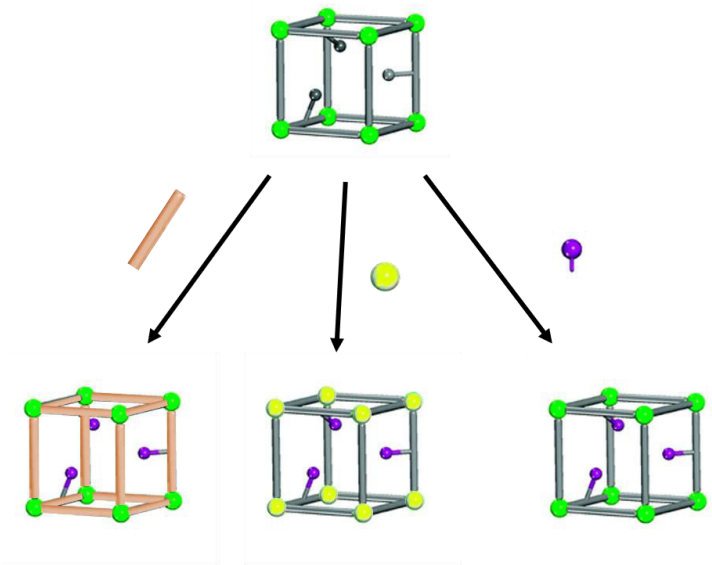
As previously discussed, the properties of MOFs can be selectively tuned by changing the ligand or metal. Another way to tune the properties of MOFs is using a technique called post-synthetic modification (PSM). PSM is where a reaction is done on the MOF *after* it has been synthesised. PSM is a way to create complex structures, increase functionality and gain control over the system. This can be done in a few different ways:

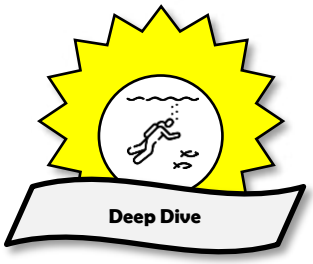
- Ligand exchange – swapping the linkers in a prefabricated MOF with a new linker. Sometimes the linker that is desired within the MOF would not survive in the harsh MOF synthesis, so switching it into the system as a post-synthetic step allows specific functional groups to be included in a system.
- Metal exchange – similar to the ligand exchange, swapping the metal in the prefabricated MOF allows the structure of the framework to remain with a new metal.
- Functional group conversion – some functional groups would either degrade in the MOF synthesis or unwantedly react with the metal, so introducing these group post-synthetically can be the only way to have them in the MOF.

Resource One Data Source

Figure 5

Graphic depicting the different types of PSM





Section D

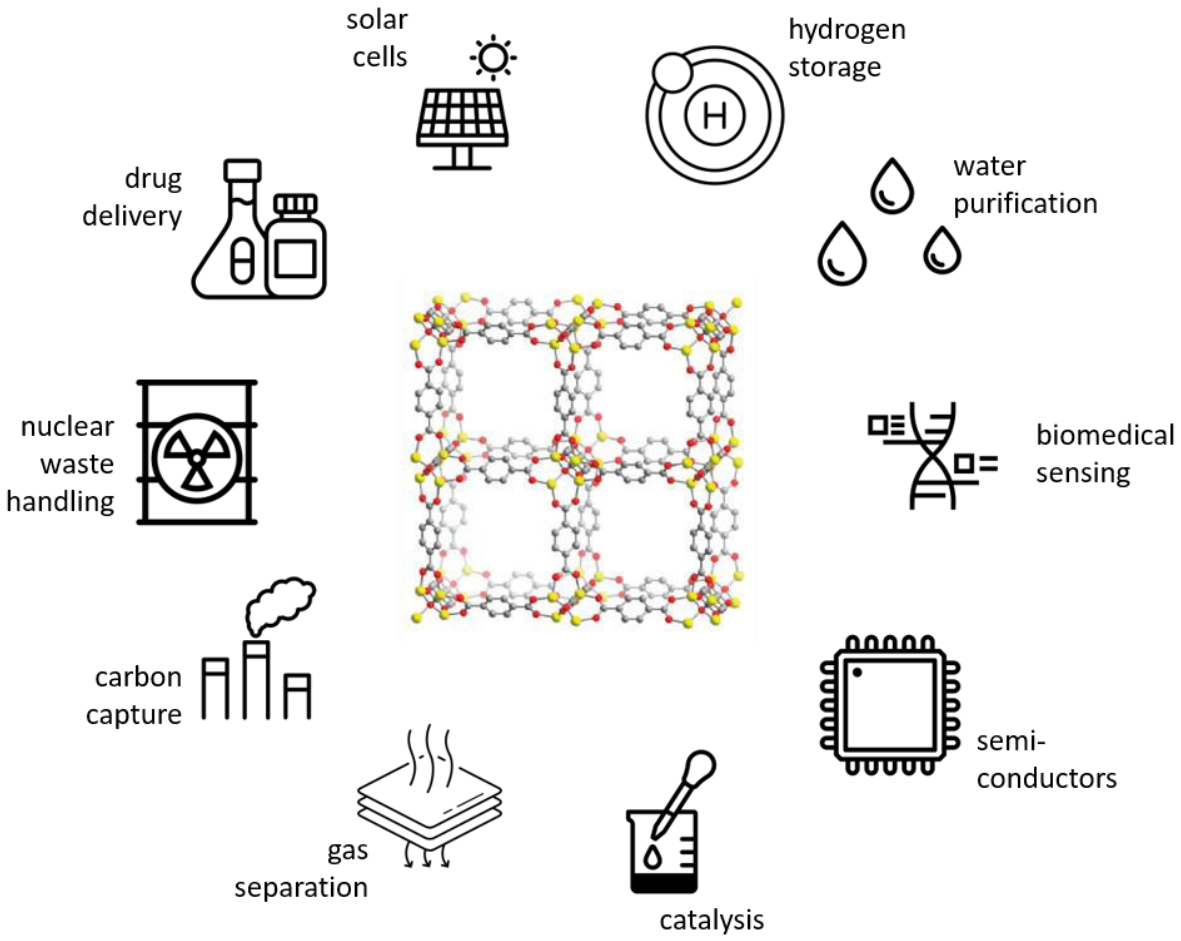
Metal-organic material applications

Because of the **tunable**, porous nature of **metal-organic materials**, they are suitable for lots of different applications, the majority of which can be seen below. Their pore space can be used to trap small molecules, for storage, transport of drugs and separation applications. The tunability of the pores allows them to selectively exclude specific molecule sizes and let others through, meaning they are useful for separation technologies. The conductive nature of **metal-organic materials** means they are excellent for electronic applications. Lastly, other functional groups on the ligands (not those bonded to the metal) can act as a catalysis site or bind to molecules in order to sense for them in solutions.

Resource One
Data Source

Figure 6

MOF applications



Resource One Activities

Activities

1. List the different types of post-synthetic modification.
2. Which group on the periodic table is most commonly used in **metal-organic frameworks**? And what is their typical coordination number?
3. Explain how a **coordination bond** works.
4. Draw a ligand that could be used to make a MOF.
5. Choose one MOF application and research why MOFs are good for that application:
    - Start by searching MOFs for .....
    - It might be good to focus on one MOF specifically from your search.

Resource One
Further Reading

Explore

- This tool allows you to build your own MOFs and explore their pore sizes.
- A short youtube video from a research group working with MOFs.
- A longer youtube video from a leading researcher in the field of MOFs (more complex ideas but a very comprehensive video):
- These Wikipedia links have loads of great detail about the topics we have covered:
  1. Metal-organic Framework
  2. Coordination polymer

Resource Two Overview

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Topic 2D materials: why losing a dimension is a good thing!

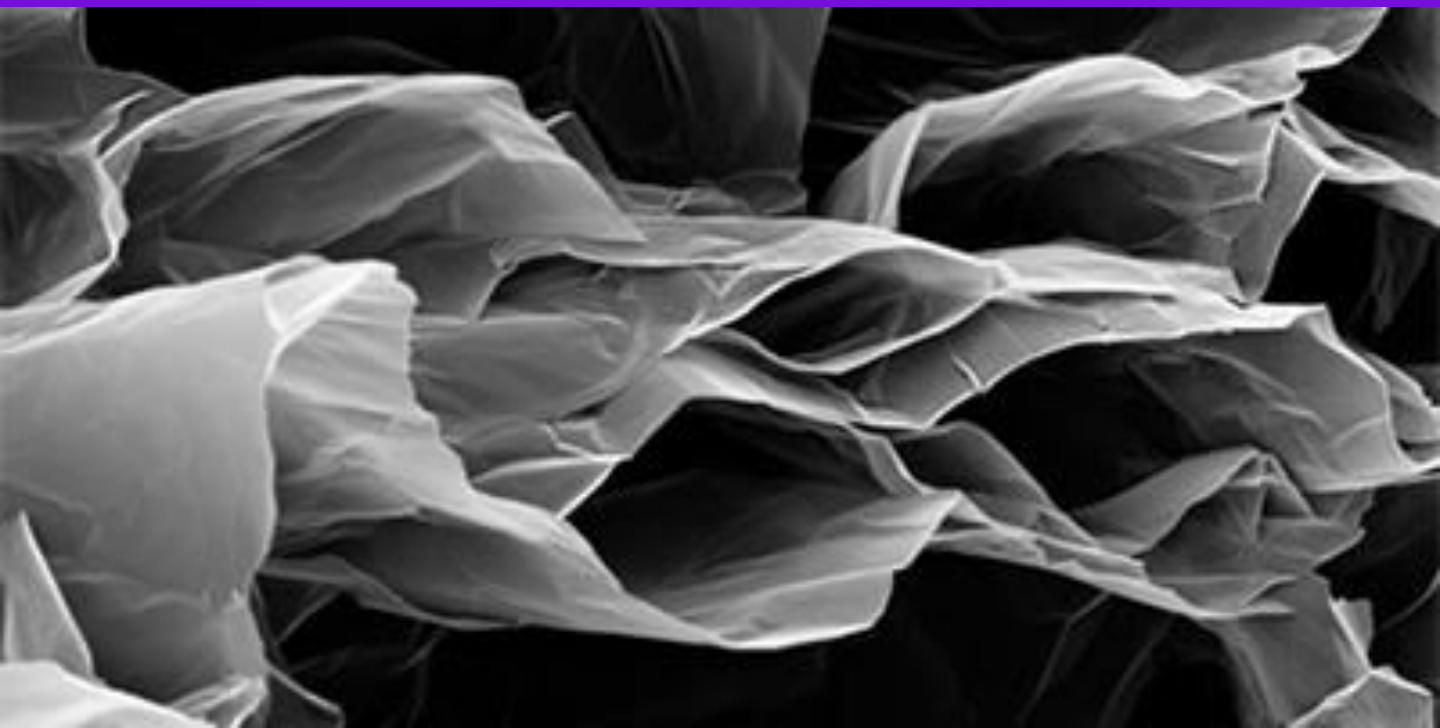
A-level Modules Bonding, Transition metals, Organic Synthesis

Objectives By the end of this resource, you will be able to:

- ✓ Understand what constitutes a **2D material** and the different types
- ✓ Describe the methods of synthesizing a **2D material**
- ✓ Explain why **2D materials** have the advantage over 3D materials in applications

Instructions

1. Read the data source
2. Complete the activities
3. Explore the further reading



Resource Two
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Section A

Different types of 2D materials

In 2004 graphene was discovered, and since then the world **of two-dimensional (2D) materials** has boomed. While graphene is the most famous 2D materials, it is by no means the only one! Before we explore some of the different types of **2D materials,** we need to first understand what is meant by 2D.

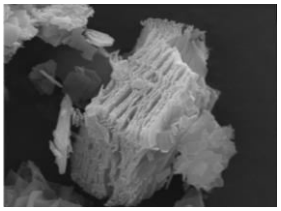
In an ideal world **two-dimensional materials** refer to crystalline solids consisting of a single layer of atoms, called nanosheets. In practice **2D materials** often do not have single atom thickness, however materials with thicknesses of up to 30 nm can still be considered as 2D.

Graphene is an allotrope (a different physical form of one element) of carbon. Covalent bonds (where two none-metal atoms share a pair of electrons) connect each carbon atom to 3 others, forming a hexagonal lattice. In addition to graphene there are lots of other single element **2D materials**, such as borophene, silicene and phosphorene.

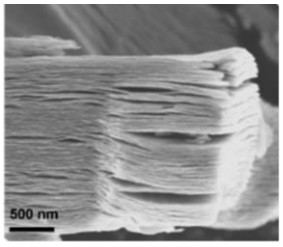
As well as single element **2D materials**, there are a many compounds that have a nanosheet structure. Transition metal dichalcogenide monolayers are comprised of a layer of transition metal atoms sandwiched between chalcogen atoms (S, Se or Te). A key feature of transition metal dichalcogenides is their giant magnetoresistance and superconductivity. Mxenes are another class of 2D inorganic compounds made from transition metal carbides, nitrides and carbonitrides. The conductive nature of Mxenes lends them to applications in energy storage and electronic devices. Boron nitride has the same hexagonal structure as graphene, however it has opposite electronic properties and is an insulator rather than conductive. Also with a hexagonal structure is 2D silica, an form of silicon dioxide, similarly to boron nitride it is an insulator.

Figure 1

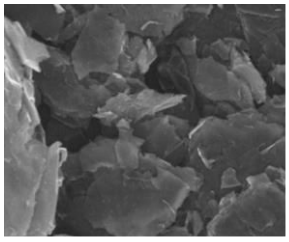
SEM images of graphene, Mxene and **metal-organic nanosheets**



Metal-organic nanosheets



MXenes



Graphene

Resource Two
Data Source

Section A

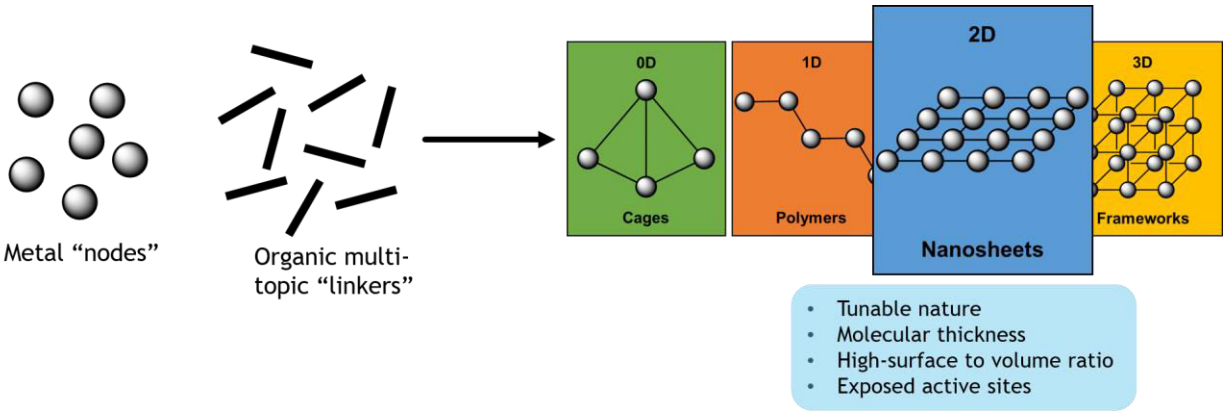
Different types of 2D materials

Metal-organic nanosheets are another type of **2D material** and a class of **metal-organic material**, they will be the focus of the rest of this resource. **Metal-organic materials** are discussed in more detail in resource one of this coursebook, however we will recap the basics now.

Metal-organic nanosheets (MONs) are the two-dimensional version of **metal-organic materials**. MONs are made up of metals and **organic ligands** bonded by **coordination bonds**. The large selection of metals and **organic ligands** with a range of different functional groups allows MONs to be synthesised to give specific properties for each application. The **tunable** nature of MONs is a huge benefit over other **2D materials** that are limited by the composite parts. In addition to the benefit of tunability over other **2D materials**, MONs have advantages over other types of **metal-organic material**. Namely their near atomic, or molecular thickness, additional exposed active sites (functional groups that can be used to adsorb compounds or as catalysis sites) and high surface-to-volume ratio (the ratio of the surface are to the volume of the material).

Figure 2

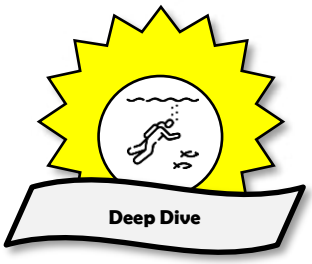
Schematic depicting metal-organic nanosheets



Resource Two
Data Source

Section B

Synthesising **metal-organic nanosheets**



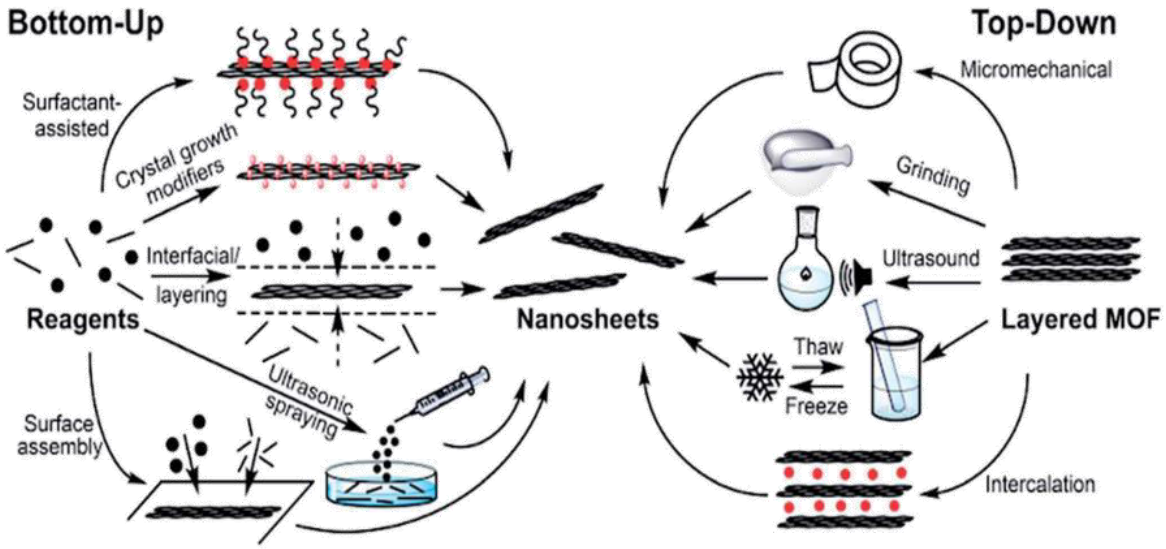
There are two categories of MON synthesis; **top-down** and **bottom up**.

Top-down synthesis is where you synthesise a layered material (e.g. a MOF), and then apply an energetic process which causes the layers to peel apart into free-standing nanosheets (usually in solution). This process is called **exfoliation** because, in this method, you start with highly crystalline, 3D layered materials. The purity of the product is very high. However, this synthesis can only be done on a small scale so the yield (amount of product) is often low and involves multiple steps.

Opposite to **top-down** is the **bottom-up** method of synthesis. This is where you use a range of techniques to force the synthesis into making free-standing nanosheets from the reagents. This method has the advantage of being single step, and can produce a high yield, however the crystallinity and purity of the product is often sacrificed.

Figure 3

A range of different **top-down** and **bottom-up** synthesis techniques



Resource Two
Data Source

Section B

Synthesising **metal-organic nanosheets**

Within these two categories of MON synthesis there are lots of different specific methods of preparing **2D materials** (see figure 3). Each method has their own additional pros and cons which need to be taken into account when choosing a synthesis method for your material.

Table 1

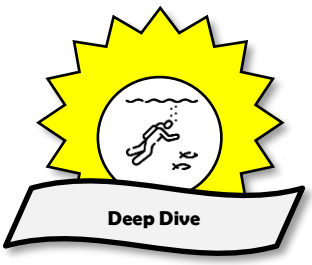
Pros and cons for **top-down** and **bottom-up** synthesis techniques

	Top-Down	**Bottom-Up**
Pros	High crystallinity, high purity	Single step synthesis, high yield
Cons	Multi-step synthesis, low yield	Low crystallinity, low purity

Resource Two
Data Source

Section C

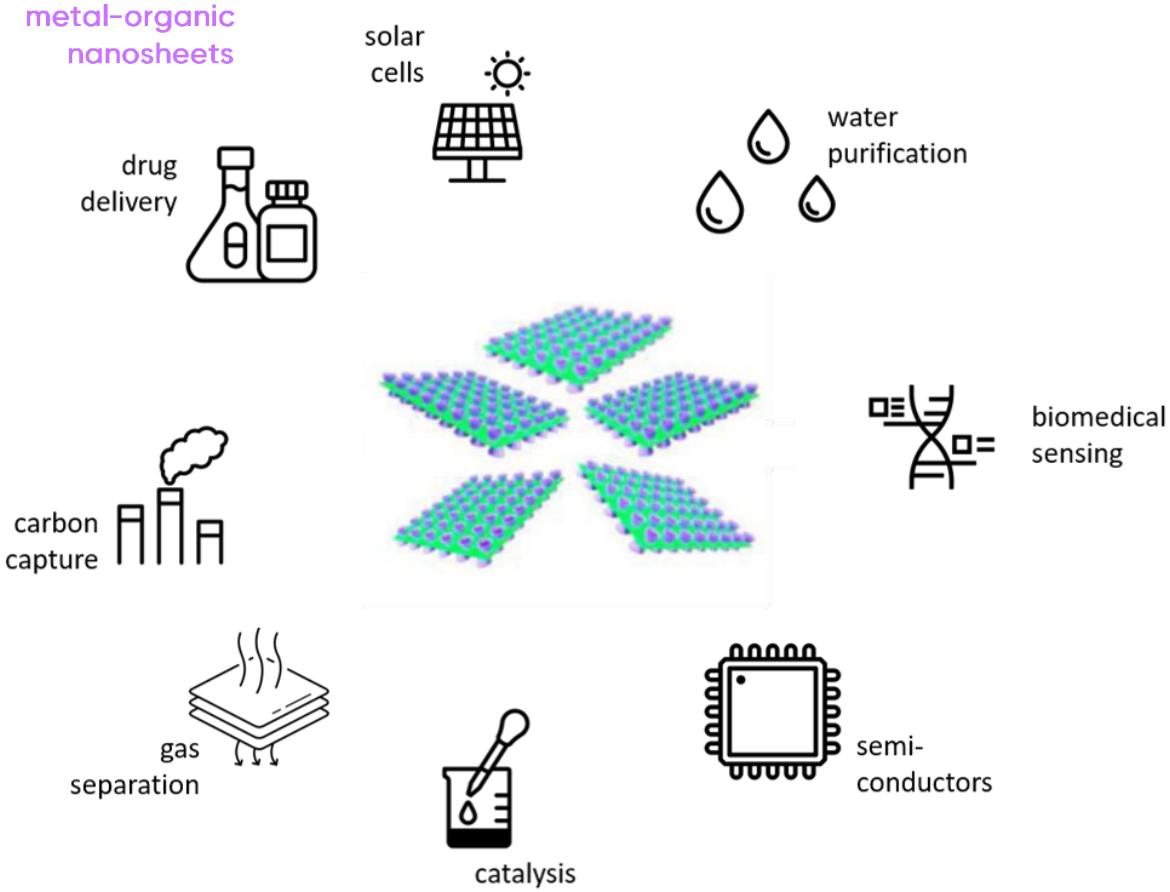
Metal-organic nanosheet applications



As with **metal-organic frameworks**, the **tunable** and porous nature of MONs lends them to many applications. However, MONs have the added advantage of being 2D. Because MONs are nearing atomic thickness, there is less material for other molecules to pass through, meaning that the flow rate in applications like water purification and gas separation is much higher. This also means that electronic devices can be made smaller and thinner. In 3D MOFs, a large amount of the function groups on the ligands, called active sites, are buried inside the structure. Whereas in MONs, because they are 2D, all of these active sites are exposed, meaning more catalytic reactions can happen or more molecules can bind to the surface. Lastly, because the surface-to-volume ratio is much higher in MONs, to get the same number of active sites for the catalysis or sensing etc to have the same effect, a much lower amount needs to be used.

Figure 2

Schematic depicting **metal-organic nanosheets**



Resource Two Activities

Activities

1. List 2 types of **top-down** synthesis and 2 types of **bottom-up** synthesis methods (see the diagram on page 24).
2. List the pros and cons of **top-down** and **bottom-up** methods.
3. Explain why 2D MONs are better than 3D MOFs for catalysis applications.
4. Explain what happens in **top-down** and **bottom-up** synthesis methods.
5. There are lots of other single element **2D materials** than graphene. Research one other single element **2D material** and present your findings to your peers or classmates.

Resource Two
Further Reading

Explore

- A BBC discovery podcast about the discovery of graphene.
- This Compound Chem infographic all about graphene.
- This Compound Chem infographic about how MOFs can be used to trap neon:
- A video about 2D materials beyond graphene (this doesn't include MONs).

Resource Three Overview

MAKE HAPPEN

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Topic Characterisation: how we look at 2D materials

A-level Modules Organic Analysis, NMR

Objectives By the end of this resource, you will be able to:

- ✓ Understand which methods of characterisation are used in both metal-organic and 2D materials
- ✓ Understand the basics of how these characterisation instruments work
- ✓ Understand what data is collected and how it can be interpreted

Instructions

1. Read the data source
2. Complete the activities
3. Explore the further reading

Resource Three
Data Source

Section A

NMR

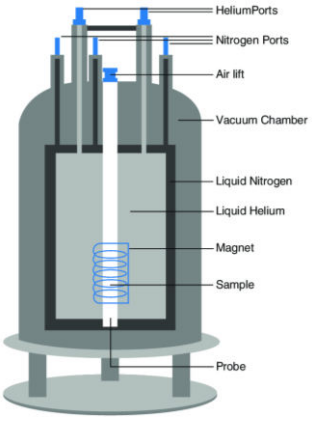
Nuclear magnetic resonance (NMR) spectroscopy is a very commonly used technique in chemistry. **NMR** gives information about the position of certain atoms within a molecule. Samples are placed in a magnetic field and nuclei are excited by radio waves, producing an **NMR** signal which is detected by sensitive radio receivers. Usually the samples used are in solution, however solid-state **NMR** is possible.

^{1}H is the most common nuclei used in **NMR** due to how sensitive it is to the **NMR** signal. However ^{2}H, ^{3}He, ^{11}B, ^{13}C, ^{14}N, ^{15}N, ^{17}O, ^{19}F, ^{31}P, ^{35}Cl, ^{37}Cl, ^{43}Ca and ^{195}Pt are also fairly commonly used in **NMR spectroscopy.**

Because ^{1}H **NMR** is the easiest and most common nuclei used, **NMR** is mainly used to characterise the **organic ligands** in metal-organic materials.

Figure 1

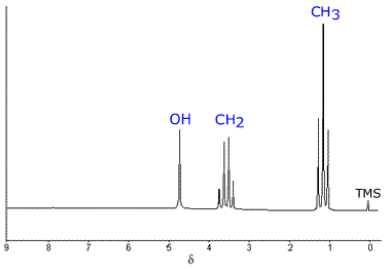
Left: Diagram of the inside of an **NMR spectrometer.** Right: Photograph of an **NMR spectrometer**



The spectra produced from an **NMR** can be used to identify the structure, functional groups and their positions within a molecule. Spectra are comprised of peaks - see example in figure 2. The position in the spectra, also known as the chemical shift, is dependent on the functional group. Peaks are then split dependent on what they are next to. Peak splitting is called multiplicity and can be a singlet, doublet, triplet, quartet and so on.

Figure 2

Example **NMR** spectra of ethanol. TMS is a standard often used in **NMR spectroscopy**



Resource Three
Data Source

Section B

IR

Infrared (IR) spectroscopy is another method of identifying the functional groups present in a molecule. An **IR spectrum** shows the absorption of a solid, liquid or gas samples in the IR region of the electromagnetic spectrum.

When **IR** light shines on a molecule the covalent bonds absorb the energy. The frequency that the bonds absorb matches the frequency that the bonds vibrate. There are a number of types vibration a bond can undergo, including stretching and bending. The frequency at which the bonds vibrate depends on the atoms at either end of the bond, therefore the absorption frequency can be related to a specific bond type.

Because the **IR** only absorbs inorganic molecules, this technique is also only used to characterise the **organic ligands** in MONs and MOFs.

Figure 3

Diagram of the inside of an **IR spectrometer**

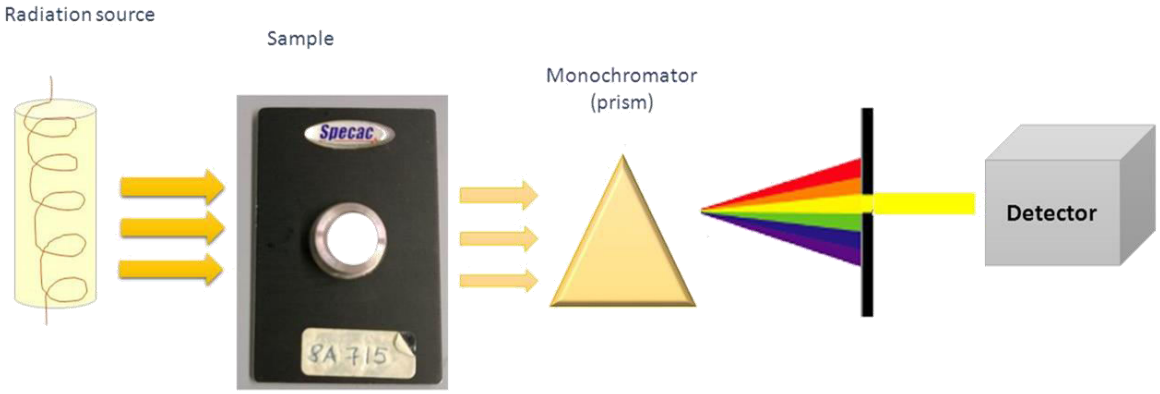


Figure 4

Photograph of an **IR spectrometer**

Resource Three
Data Source

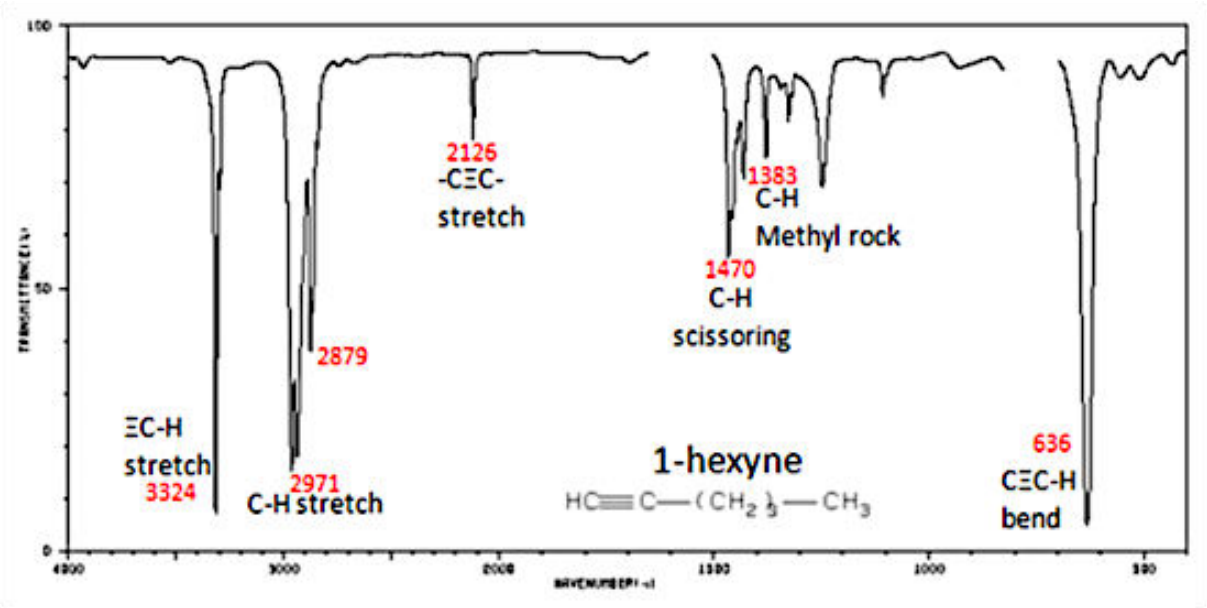
Section B

IR

Large tables of IR frequencies for all the different functional groups that are active in the IR region are used to label the different peaks in the spectrum. These peaks are called bands in IR spectroscopy. Because IR only shows the functional groups present and not their position within the molecule, IR spectra are typically used to confirm an already known structure.

Figure 5

Example of a labelled IR spectrum of 1-hexyne, including the type of vibration the bonds undergo.



Resource Three
Data Source

Section C

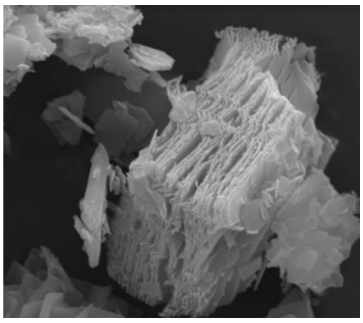
Microscopy

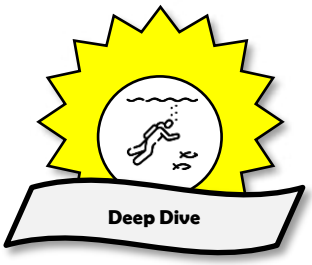
There are many types of microscopy used in chemistry, but we are going to focus on the two types mainly used for **metal-organic nanosheets**; scanning electron microscopy and atomic force microscopy.

A scanning electron microscopes (SEM) is a type of microscope that uses a focussed beam of electrons to scan a surface. When the electron beam hits the surface the atoms on the surface become excited and then emit electrons which are detected and used to create the image. The normal resolution of an SEM is around 10 nm.

Figure 6

Left; scanning electron microscope instrument
Right; SEM image of stacked MONs

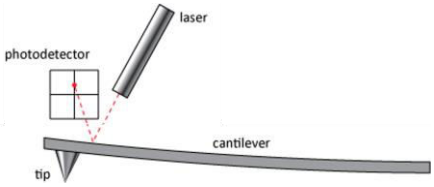


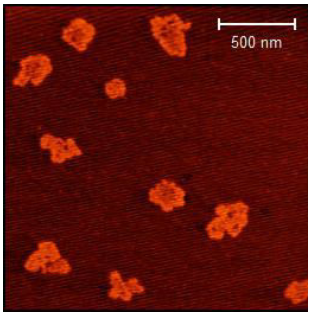


An atomic force microscope (AFM) is another type of microscope that probes surfaces using an atomic tip. This incredibly small (atomic sized) tip is attached to a cantilever, which scans the surface, tapping as it passes over the surface. A laser is focussed on the back on the cantilever and the changes in the reflection is detected and used to create an image. It is possible to get images on even an atomic level!

Figure 7

Left; atomic force microscope instrument
Top right; diagram of how an AFM records images
Bottom right; AFM image of MONs





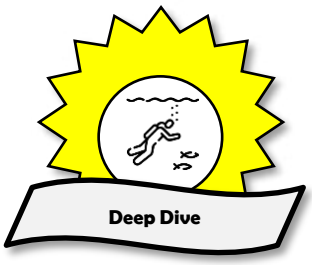
Resource Three
Data Source

Section D

X-ray diffraction

There are two types of **X-ray diffractometer**; single crystal **X-ray diffractometers** (SCXRD) and powder **X-ray diffractometers** (PXRD).

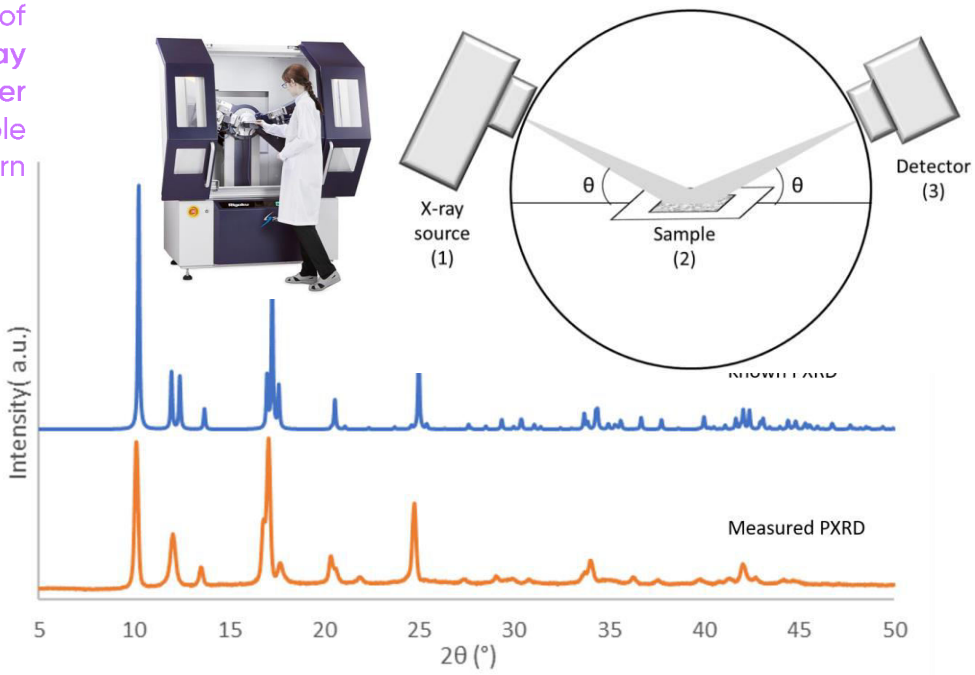
As the name implies, SCXRD requires a single crystal sample, this can be hard to obtain in real laboratory situations. Whereas PXRD only needs a powder sample of a crystalline material – such as MONs.



In **X-ray diffractometers**, an X-ray source emits radiation that penetrates the sample from a range of angles. The atoms in the crystalline sample deflect the X-rays and these deflected X-rays are detected. Because crystalline materials have a regular arrangement of atoms, they will deflect in a specific pattern. When making a new material, patterns from known materials with the same or similar crystal structures can be compared to the measured pattern from the synthesised material. When synthesising new **metal-organic nanosheets** PXRD is arguably the most important characterisation method. Ensuring the structure of the material remains the same each synthesis and after **exfoliation** is very important. PXRD can also be used to track changes in structure during post-synthetic modification experiments.

Figure 8

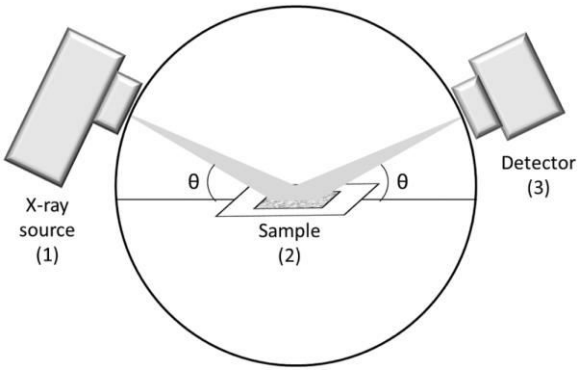
Left; A powder **X-ray diffractometer**
Top right; Diagram of the inside of an **X-ray diffractometer**
Bottom-right; Example of a PXRD pattern

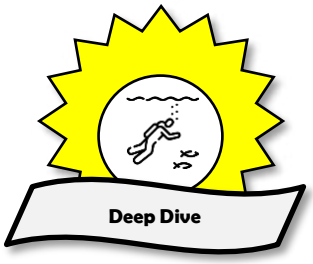


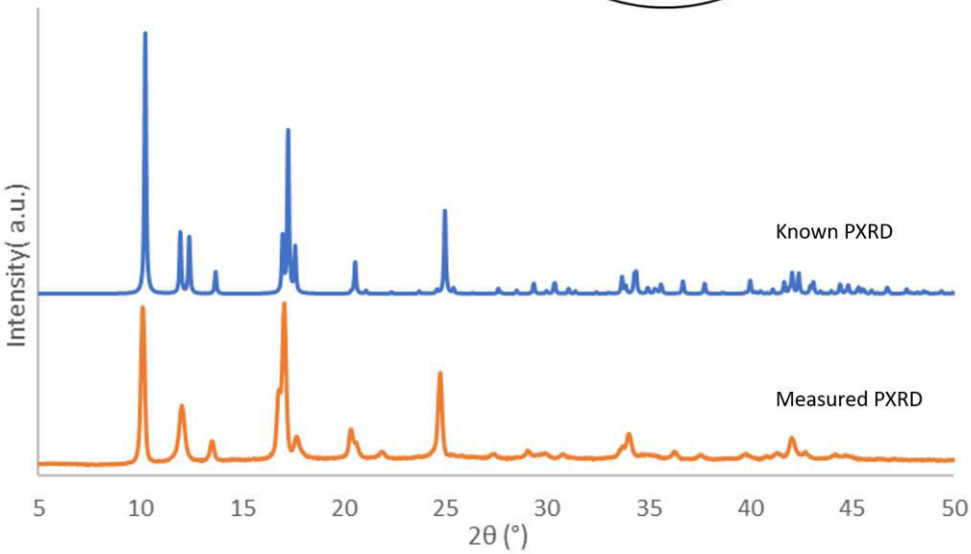
Resource Three
Data Source

Figure 8

Left; A powder **X-ray diffractometer**
Top right; Diagram of the inside of an **X-ray diffractometer**
Bottom-right; Example of a PXRD pattern







Resource Three Activities

Activities

1. What is the resolution on a scanning electron microscope (SEM)?
2. What type of sample do SCXRD and PXRD measurements require?
3. ^{1}H is the most common type of nuclei used in **NMR spectroscopy**. Name 5 other commonly used nuclei in **NMR**
4. What type of sample can be used in **IR spectroscopy**?
5. Explain how an atomic force microscopy (AFM) works.
6. What are the range of wavelengths for infrared and X-ray radiations? Research this independently.

Resource Three
Further Reading

Explore

- This bitesizebio article about NMR spectroscopy.
- A BBC bitesize guide on IR spectroscopy.
- A bit of X-ray crystallography history.
- This article with some of the most spectacular SEM images:

Resource Four Overview

MAKE HAPPEN

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Topic Polymer basics

A-level Modules Polymers, Bonding, Organic Synthesis

Objectives By the end of this resource, you will be able to:

- ✓ Understand the basics of **polymers** and how they are synthesised
- ✓ Describe the different applications **polymers** can be used for
- ✓ Explain the type of bonding present in **polymers** and how cross-linking can affect the structure

Instructions

1. Read the data source
2. Complete the activities
3. Explore the further reading

Resource Four
Data Source

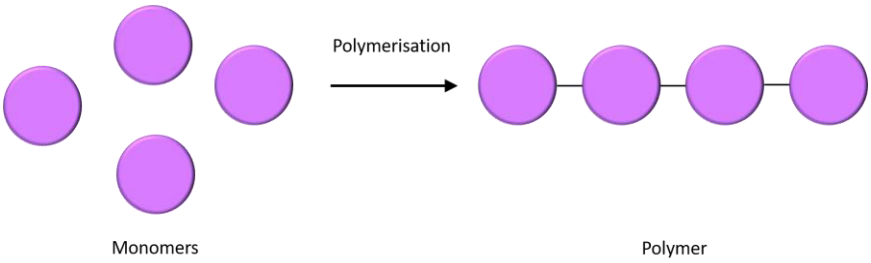
Section A

Back to basics: what is a polymer?

A **polymer** is a material made up of large molecules composed of repeating building blocks. These building blocks are called **monomers**. Another term for a large molecule is a macromolecule. The reaction of **monomers** joining together to form a **polymer** is called **polymerisation.**

Figure 1

Diagram of **polymerisation**



Polymers come in many forms, both synthetic and naturally occurring. One example that you will be familiar with is plastics! Other synthetic examples include rubber, latex and Teflon. Some natural examples that you may not realise are **polymers** include wool, silk and DNA!

Figure 2

Examples of **polymers**

Right; Teflon pan (top), latex gloves (bottom)

Left; DNA (top), raw wool (bottom)

Resource Four
Data Source

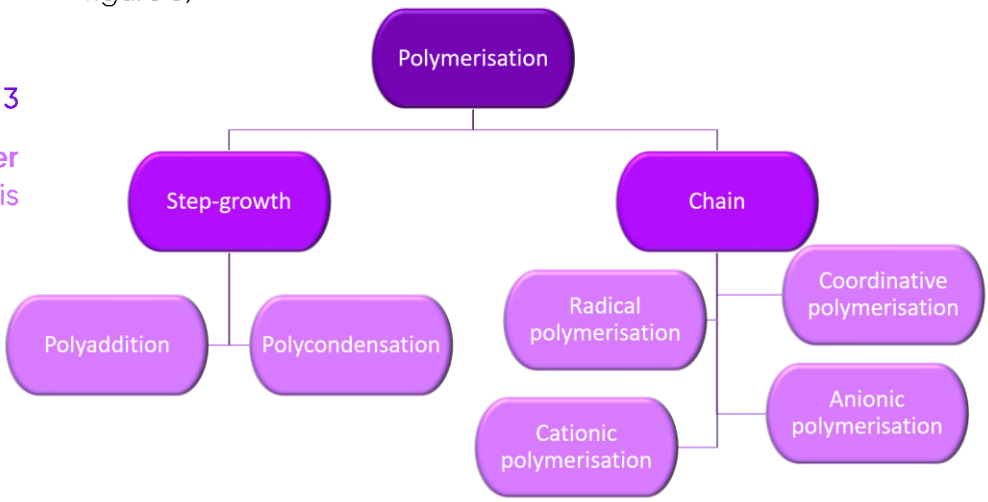
Section B

Polymer synthesis

As we now know, **polymer** synthesis is called **polymerisation.** There are two types of **polymerisation**; step-growth and chain. Within those two classes are further sub-classes (see figure 3)

Figure 3

Types of **polymer** synthesis



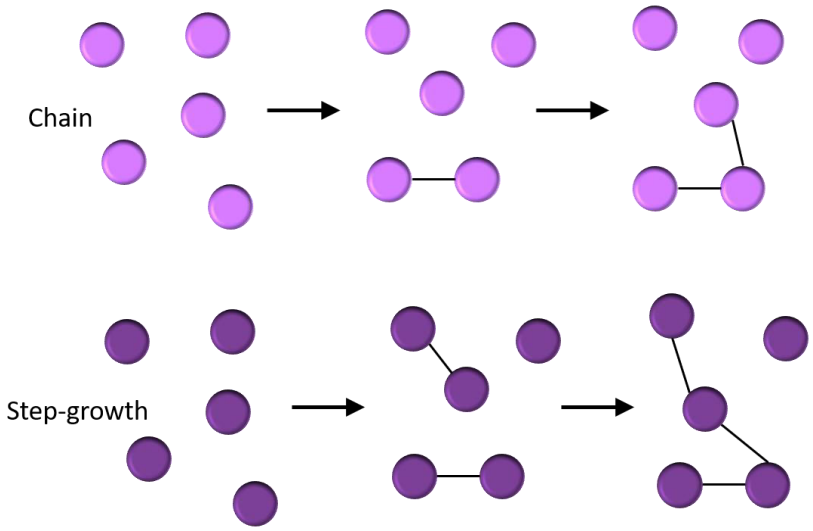
In both step and chain synthesis, **monomer** units covalently bond to one another to form a **polymer** chain or network. In chain **polymerisation**, **monomers** are added one at a time. In step-growth **polymerisation** chains of **monomers** can combine with each other as well. Each **monomer** that is included in a **polymer** is called a repeat unit, the total amount of repeat units is the chain length.

Resource Four
Data Source

Figure 4

Step-growth vs. chain polymerisations

In both step and chain synthesis, **monomer** units covalently bond to one another to form a **polymer** chain or network. In chain **polymerisation**, **monomers** are added one at a time. In step-growth **polymerisation** chains of **monomers** can combine with each other as well. Each **monomer** that is included in a **polymer** is called a repeat unit, the total amount of repeat units is the chain length.



Active Reading

Catalysts can be used in all types of **polymerisation** reaction to speed up the reaction process. Catalysts do this by providing an alternative reaction route with lower activation energy.

Resource Four
Data Source

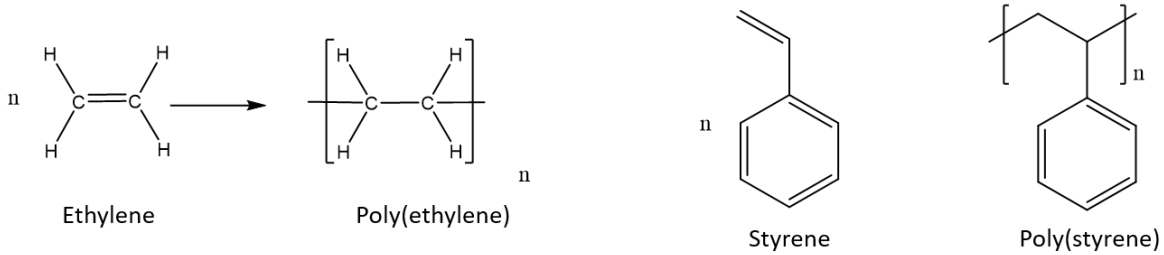
Section C

Polymer structure

When drawing the chemical structure of a **polymer**, often the chain length is too long to draw the entire structure out. Therefore we use the notation seen in figure 5. Instead of drawing each repeating unit, a single repeating unit is simply encased by brackets. The "n" denotes how many repeating units are present. The name of each **polymer** reflects the **monomer** used, therefore if propylene was the **monomer**, then the **polymer** would be called poly(propylene).

Figure 5

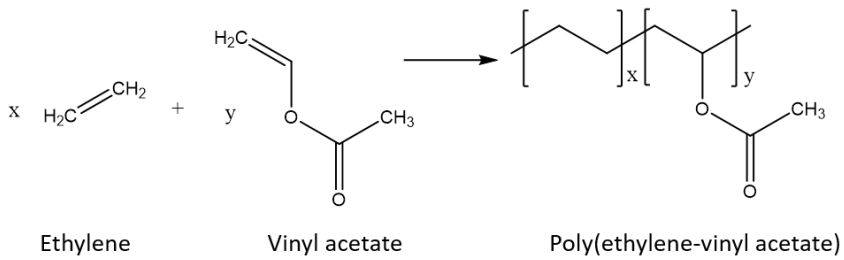
Examples of **polymer** notation

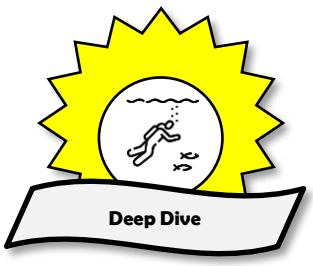


When only one **monomer** is used this is called a homopolymer. When two or more different **monomers** are used in one **polymer** chain this is called a copolymer.

Figure 6

Example of copolymer notation

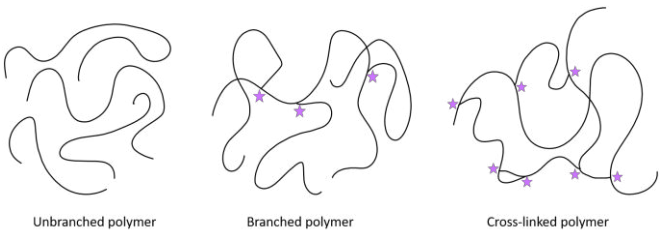




Once the **polymer** chains have formed you need to consider the **polymer** architecture. A **polymer** chain can either be branched or unbranched. Chains can also cross-link, this is where one **polymer** chain links to another. The **polymer** architecture affects the **polymer's** physical properties such as viscosity, solubility, porosity, mechanical strength and glass-transition temperature.

Figure 7

Polymer architectures – stars indicate where there is a bond, either a new chain branching off or a cross-linked chain



Resource Four
Data Source

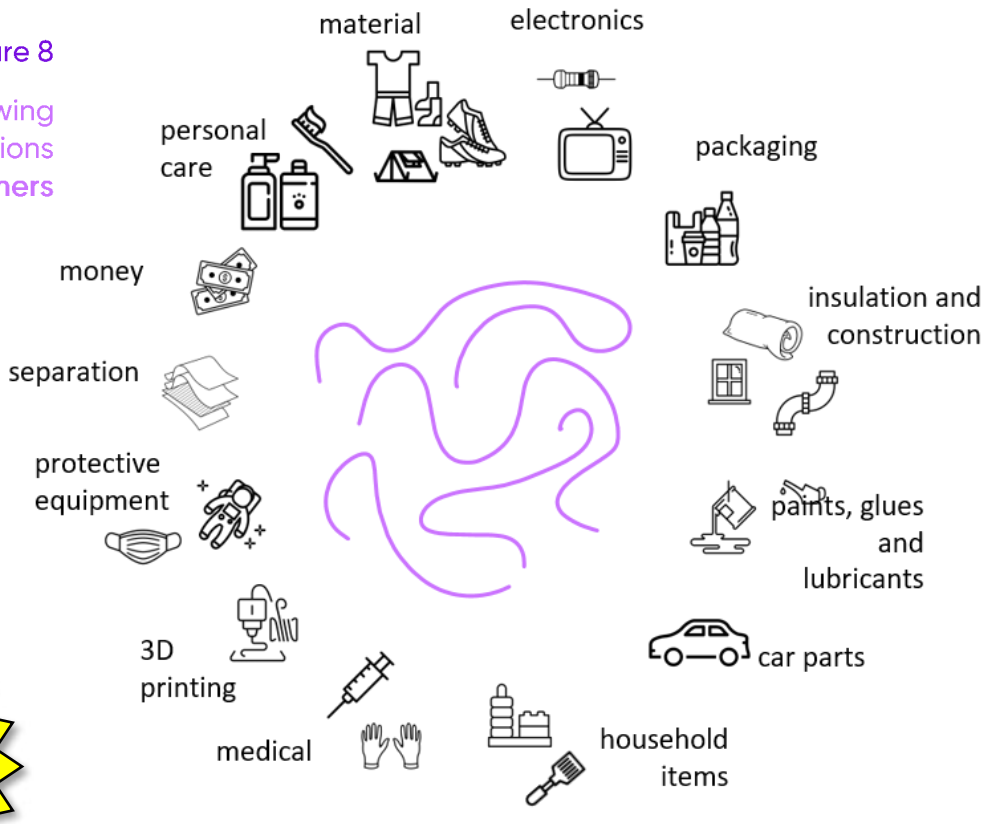
Section D

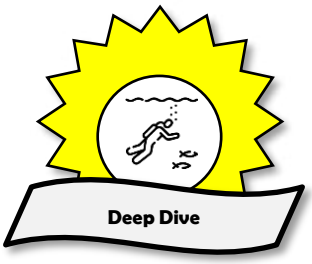
Polymer applications and examples

Polymers are one of the most versatile branches of chemistry in the world. Without polymers the modern world would look incredibly different. Due to their relative low cost, low energy manufacture and easy to process into different products, nowadays polymers are chosen over more traditional materials like wood and metal for a whole host of applications.

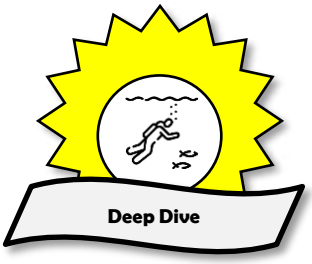
Figure 8

Diagram showing different applications of polymers





Resource Four
Data Source



There are a near infinite number of **polymers**, especially when you consider the possible combinations of **monomers** in copolymers. There are however, some very common **polymers** that you will find in everyday life. These **polymers** are some of the first synthesised and have had extensive research carried out on them.

Table 1

Common **polymers**, their key properties and uses

Polymer	**Properties**	**Uses**
Polyethylene (PE)	Chemically inert, thermal insulator	Toys, bottles, plastic bags
Polypropylene (PP)	Acid resistant, mechanical strength	Car parts, food containers, dishware
Polystyrene (PS)	Thermal insulator	Plastic cutlery, packaging
Polytetrafluoroethylene (PTFE)	Low friction, chemically inert	Non-stick pans, insulation
Polyvinyl chloride (PVC)	Flame retardant, chemically inert	Pipes, clothes, flooring
Polyamide (PA)	Flexible, low friction	Clothing, **membranes**, flooring

Resource Four Activities

Activities

1. Define a **polymer.**
2. Which type of bonding is present in **polymers**?
3. Explain why **polymers** are often selected over traditional materials such as wood.
4. Explain the difference between a homopolymer and a copolymer.
5. Choose one of the seven common **polymer** examples and research them in further depth – present your findings to your peers.

Resource Four
Further Reading

Explore

- BBC bitesize revision on polymers.
- A crash course video on polymers.
- This ScienceNewforStudents article about polymers.

Resource Five Overview

MAKE HAPPEN

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Topic What even is a membrane!?

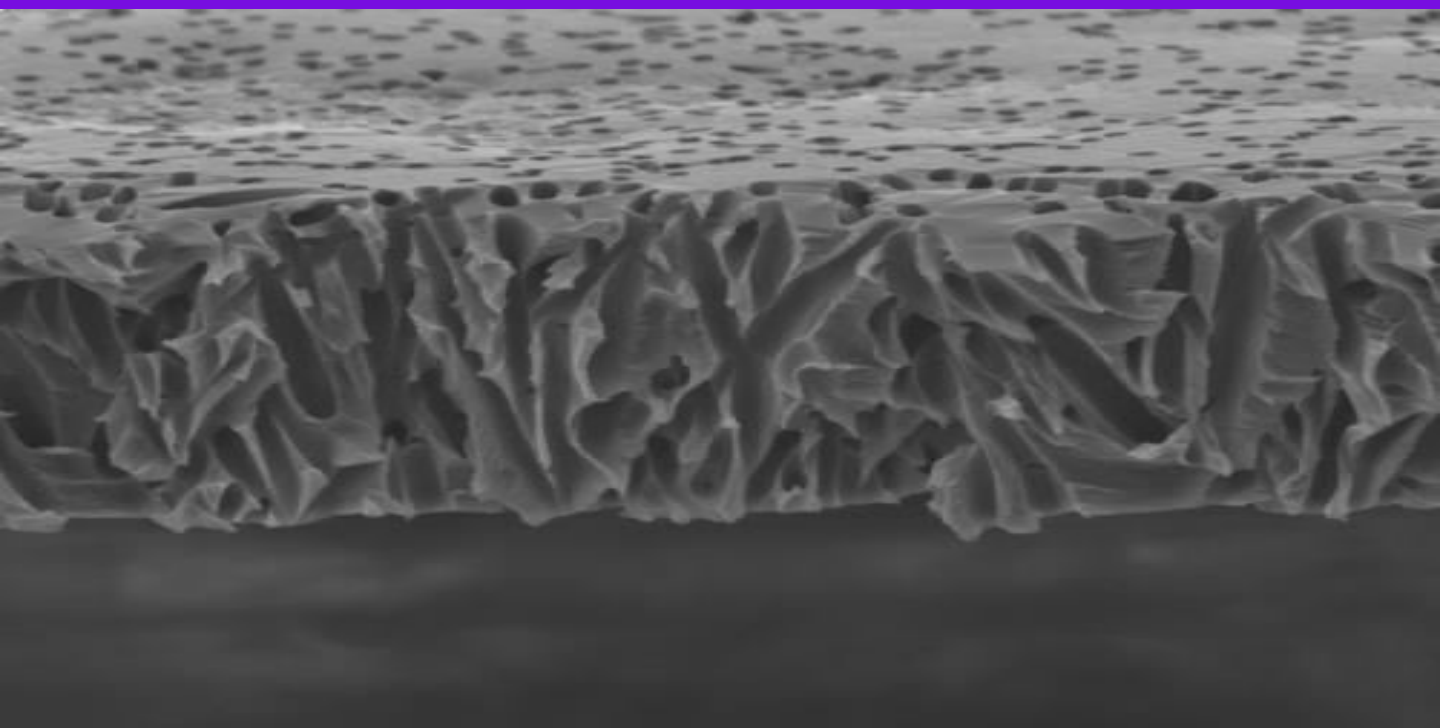
A-level Modules Polymers, Transition Metals, Environmental Science

Objectives By the end of this resource, you will be able to:

- ✓ Understand the different types of **membranes** and their uses
- ✓ Be able to describe what a composite **membrane** is
- ✓ Be able to explain the benefit of using mixed matrix **membranes**

Instructions

1. Read the data source
2. Complete the activities
3. Explore the further reading



Resource Five
Data Source

Section A

Membrane types

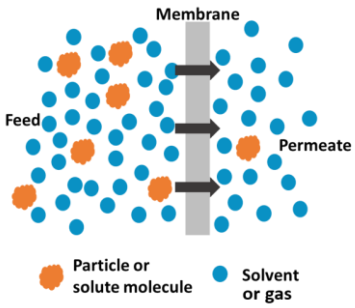
A **membrane** is defined as a selective barrier. In other words it allows some things to pass through but stop others (figure 1). There are two broad types of **membrane**; biological and synthetic.

Biological **membranes** are **membranes** found naturally in biology, such as cell **membranes** and nucleus **membranes**. Synthetic membranes are **membranes** that have been created in a lab for specific separation purposes. In this resource we are going to focus on synthetic **membranes**.

Within the broad category of synthetic **membranes** there are a few sub-categories; organic, inorganic and composite.

Figure 1

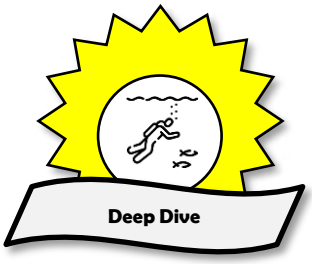
Diagram of a membrane



Organic **membranes** are made of entirely organic compounds, such as **polymers.** The majority of commercial **membranes** are made from **polymers**. This is because of the low cost, ease of processing, porosity and flexibility of many **polymers**.

Inorganic **membranes** are made from inorganic materials. These can range from ceramics to glassy materials to **metal-organic materials**. These **membranes** are porous, stable in acids and strong solvents, have excellent thermal stability and can be **tunable**.

Both of these **membranes** have their pros, however the performance of all **membranes** is limited from the same trade off: *flux vs selectivity*.



Flux is how fast the thing that is being filtered flows through the **membrane**. **Selectivity** is how well the **membrane** rejects the unwanted molecules. Ideally **flux** is fast and **selectivity** is high, but that is not always the case.

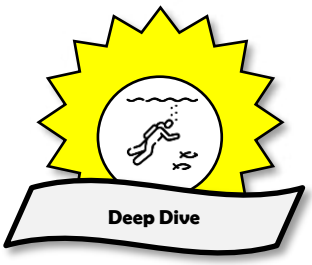
One of the ways to combat this trade off is by combining organic and inorganic materials. This is called a composite material. Composite materials can offer the best of both worlds, the flexibility and ease of processing of **polymers** and the stability and tunability of inorganics.

Resource Five
Data Source

Section B

Membrane applications

Membranes can be used for a variety of types of separation. **Synthetic membranes** are either used to separate gases or liquids. In gas separation applications, there is often a mixture of different gas molecules that need to be separated so that each individual gas can be reused. A common use for gas separation **membranes** is for carbon capture – capturing waste carbon dioxide to prevent it entering the atmosphere.

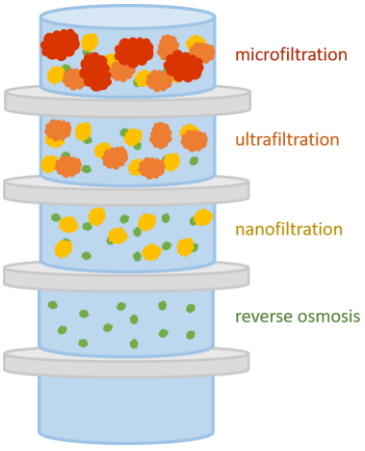


Synthetic **membranes** can also be used for liquid separations. These **membranes** filter particles out of either organic solvents or more commonly out of water. **Membranes** can filter lots of different pollutants from water, and depending on the size of the pollutant the filtration type changes.

The largest filtration type is called microfiltration. Microfiltration removes particles larger than 0.1 µm; these can be suspended particles and bacteria. Next is ultrafiltration, able to remove particles larger than 0.01 µm such as dye molecules, proteins and viruses. The penultimate filtration type is nanofiltration, this can remove particles larger than 0.001 µm. Nanofiltration can remove salts, pharmaceutical molecules and amino acids. The smallest filtration type is called reverse osmosis, removing particles down to 0.0001 µm in size. Reverse osmosis is mainly used for **desalination** – removing salt from water.

Figure 2

Diagram showing the different types of water filtration **membranes**



Resource Five
Data Source

Section C

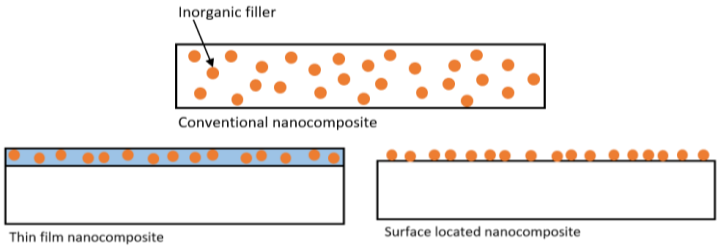
Mixed matrix membranes

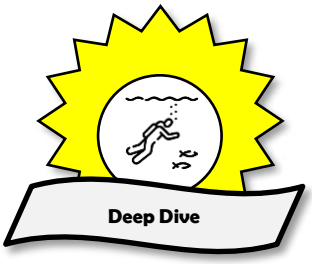
Mixed matrix membranes (MMMs) are a specific type of composite **membrane**. **Mixed matrix membranes** consist of inorganic fillers dispersed in a **polymer** matrix. A **polymer** matrix just means the **polymer** that is used to hold a filler. Inorganic fillers can include ceramics, silica and **metal-organic materials**, commonly these fillers are nanomaterials. Nanomaterials are particles or constituents of nanoscale dimensions.

There are a few ways of making **mixed matrix membranes.** Figure 4 shows the different types. Conventional nanocomposites are made when nanomaterials are mixed with the **polymer** and then the membrane is cast. Thin film nanocomposite is where nanomaterials are incorporated in a **polymer** layer that is synthesised on top of a support layer. Lastly, surface located nanocomposites are where pre-prepared by nanomaterials are deposited on top of a **membrane** support layer.

Figure 4

Diagram showing the different types of mixed matrix membranes





While other inorganic materials, such as alumina, silica and ceramics are good fillers for **MMMs,** due to their completely inorganic nature they often do not mix well with **polymers**. This leads to particles clumping and defects forming in the **membrane. Metal-organic materials**, specifically MOFs and MONs (see resource 1 for a recap on these materials), have **organic ligands** as well as inorganic **metal centres** meaning they have much better compatibility with the **polymer** matrix. **Metal-organic nanosheets** have the added benefit of being 2D, meaning the MMM can be thinner and therefore the gas or water can flow through faster. Lastly, MONs are more **tunable** than other inorganic materials, giving better control over the selectivity. Adding MONs provides another way to control how the **membrane** rejects pollutants.

Resource Five Activities

Activities

1. What are the synthetic **membrane** subcategories?
2. List 3 types of **mixed matrix membrane.**
3. What is the trade off that limit's **membrane** performance?
4. Explain why composites offer "the best of both worlds".
5. Explain the benefits MONs have over other inorganic fillers in **MMMs.**

Resource Five
Further Reading

Explore

- Wikipedia has lots of informative articles about all the different membranes discussed in this resource, starting with synthetic membranes.
- This article about making graphene mixed matrix membranes for removing salt from water.
- An article about designing gas separation membranes:

Resource Six Overview

MAKE HAPPEN

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Topic Why we need water purification

A-level Modules Environmental science

Objectives By the end of this resource, you will be able to:

- ✓ Understand the water pollution problems that face the planet
- ✓ Describe the different pollutants in fresh water
- ✓ Explain how **mixed matrix membranes** can be used to solve the water problems facing the planet

Instructions

1. Read the data source
2. Complete the activities
3. Explore the further reading

Resource Six Data Source

Section A

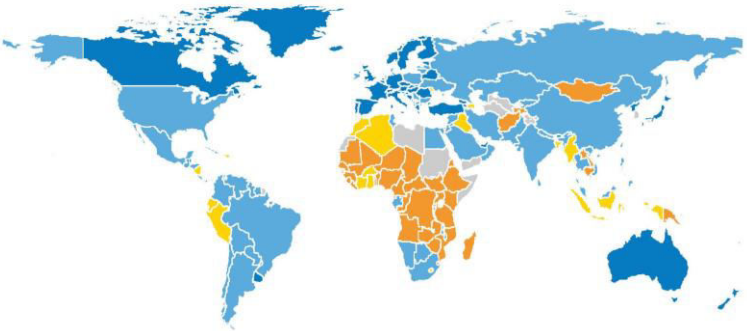
Water purification: why do we need it?

Clean, safe drinking water is essential for all life on earth and it is becoming a dwindling resource due to growing populations, industrialisation and climate change.

Having clean, fresh water coming directly out of a tap is something we take for granted, however globally over 2 billion people use contaminated drinking water sources (see Figure 1).

Figure 1

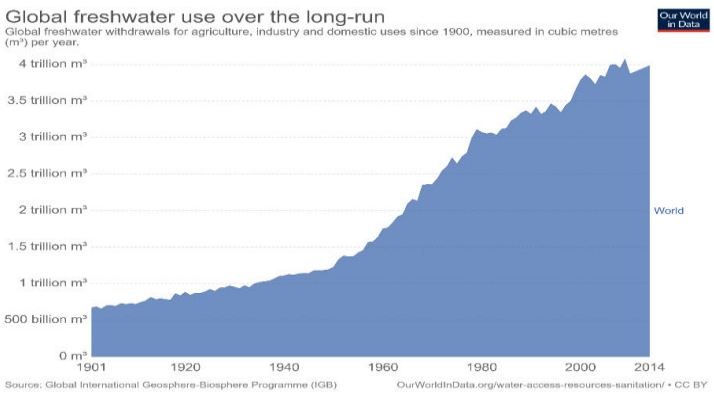
Map of the world highlighting areas with unimproved drinking water sources (orange being highest percentage of unimproved water sources, dark blue because the lowest percentage of unimproved)



In addition to drinking water, we need fresh water for many industrial processes. Industrialisation has increased the demand for fresh water in these processes and increased wastewater production. It is expected that industrial water consumption will increase by 50% from 1995 to 2025.

Figure 2

Graph of industrial fresh water consumption



Despite over 70% of the earth's surface being covered by water, only around 0.8% of this is freshwater. Due to this, and the growing fresh water demand, alternative water sources need to be explored. This includes filtering the salt out of seawater, and removing waste from the wastewater produced in industrial processes. This is where **membrane** technology can help!

Resource Six
Data Source

Section B

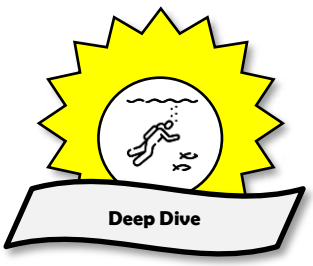
What can we filter out of water?

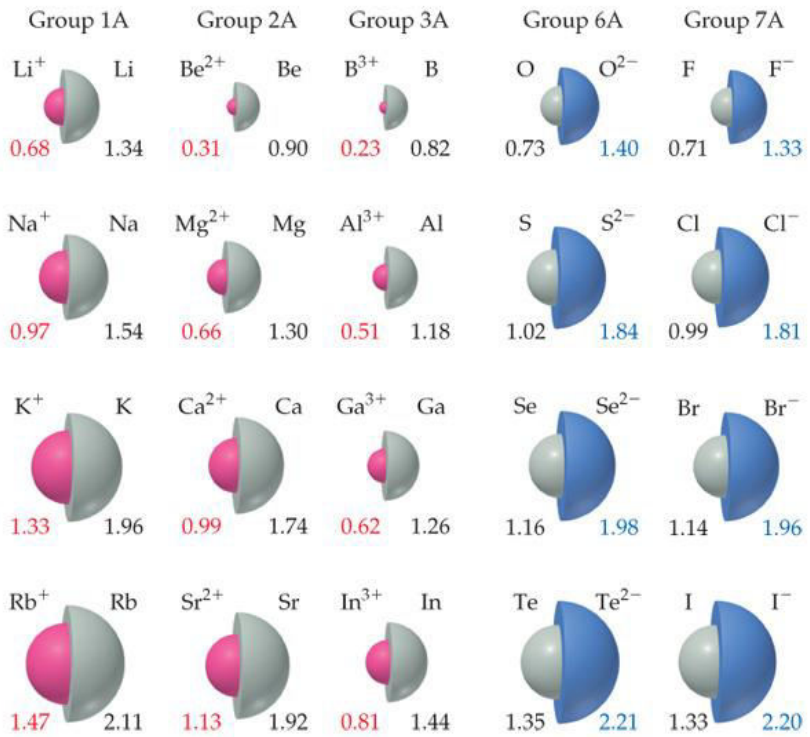
The process of removing particles and pollutants from water is called water purification. There are a number of water purification applications that are at the forefront of research at the moment.

Desalination is the removal of salt from water. This is a key challenge for water purification technologies because when salts are dissolved in water they separate into their constituent ions. These ions are very small, and thus very hard to filter out of water. A quick, easy method of **desalination** could provide drinking water to many developing countries without regular access to fresh water sources.

Figure 3

Example ionic (left) and atomic (right) radii, in nanometres





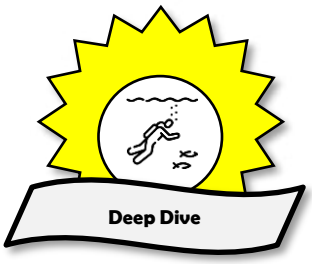
The other main water purification challenge is the removal of industrial pollutants from wastewater. This can include but is not limited to pharmaceutical molecules, organic dye molecules, antibiotics, oils and microplastics. These can range anywhere from 0.1 to 0.001 µm in size.

Resource Six Data Source

Section C

Solutions

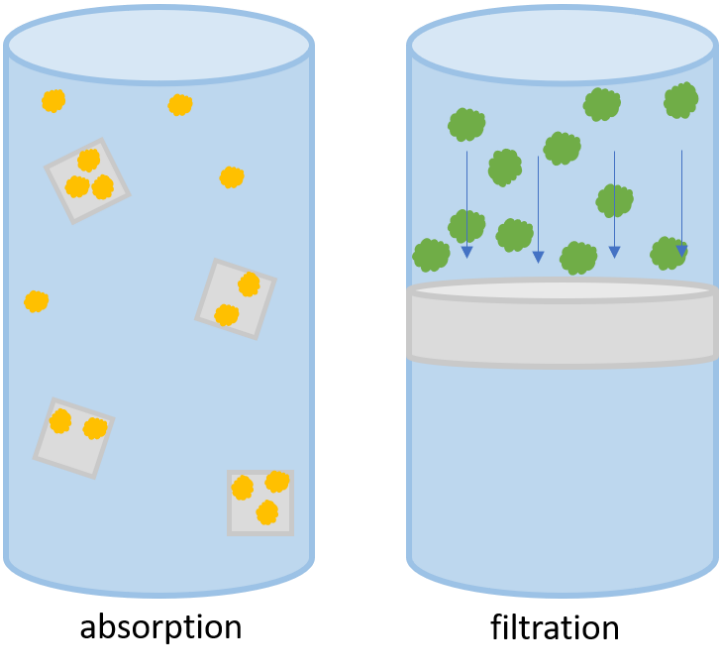
There are two ways of removing the majority of pollutants from water; absorption compounds and filtration **membranes**.



Absorption uses compounds (usually solid particles such as MOFs) with either active sites or pore spaces. An active site is a group within a compound that the pollutants can attach to. This is either through physical bonds and forces, such as hydrogen bonding and intermolecular forces, or chemical bonds like covalent bonds. When compounds have pore spaces, this means there are voids within the compound that particles can get trapped in. Often absorption compounds have a mixture of both active sites and pore spaces. This type of compound can be an effective water purification method, however once a particle is absorbed to an active site or within a pore, that site has been used up. Once all the sites have been used by pollutants the compound can no longer remove anything else from the water. Meaning this method has a finite lifetime.

Figure 4

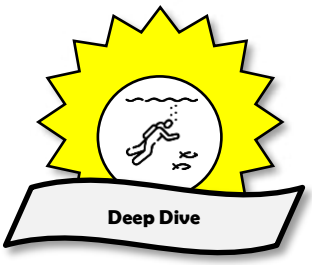
Schematic of the mechanisms of absorption and filtration separation techniques



Resource Six Data Source

Section C

Solutions



Filtration works by a principle called size exclusion. This is where the holes or pores in the **membrane** are small enough to exclude the pollutant but large enough to allow water to flow through. Because size exclusion only prevents the pollutant molecules from passing through based on their size, there are no active sites to get used up, so in theory filtration membranes could be used infinitely. In practice however, this is not quite the case. After a certain amount of time the pollutants that have been rejected by the membrane build in concentration and start to block the flow of water through the membrane. This is called fouling and is one of the main challenges facing membrane technologies.

The other challenge facing membranes is the trade off between **flux** and **selectivity**. A balance must be struck between having a fast flowing system (high **flux**) and a highly **selective** system (rejects everything we want it to). This is where **metal-organic nanosheets** and **mixed matrix membranes** come in. Utilising the low cost, easy to process, flexible **polymer membranes** and the highly **tunable**, ultrathin, porous MONs – we should be able to create the ideal water purification **membrane!**

Figure 5

Image of an industrial water filtration plant

Resource Six Activities

Activities

1. How many people worldwide do not have access to an uncontaminated water source?
2. What are the two ways to remove pollutants from water?
3. List 2 things we would want to filter from water.
4. Explain how absorption works in terms of water purification.
5. Explain how the size exclusion effect works in terms of water purification.

Resource Six
Further Reading

Explore

- The World Health Organization pages on water, sanitation and hygiene.
- This BBC bitesize guide to how can scientists help improve the supply of potable water?
- An article on the latest water purification technologies (this goes beyond the solutions we covered).

References

- Water statistics from the World Health Organization.

Final Reflection Activity

Deep Dive

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Overview

Make a scientific poster

Posters are a great way to communicate your research at scientific conferences. These posters are usually colourful and contain lots of images, graphs and figure to get the point across. When you present a poster at a conference, lots of people put their posters up and stand next to them so that other attendees can walk around and ask questions to presenters about the research on their poster. Most posters contain an introduction, methods, results and conclusions section, along with references. However, these sections are not strict guidelines as posters can be a good way to introduce new ideas and topics. Because everyone is just wandering around a lot of posters it is good to make yours eye-catching, so more people come to discuss your research.

Objectives

- ✓ Take what you have learnt in this pack to create an eye-catching, informative scientific poster
- ✓ Use computer skills to create the poster, PowerPoint is often the best way to make these posters
- ✓ Present your poster to your peers to improve your communication skills and solidify your knowledge

Instructions

Research scientific posters on google to see how these posters are presented.
Using the entire pack, create a poster that addresses the title "How can we improve water purification using 2D materials".
Aim to include explanations of:

- What 2D materials, polymer/composite membranes and water purification all are
- The global need for water purification

You may also choose to include any sections of the pack in more detail based on your own interests and independent research.
Make your poster on PowerPoint in either A4 or A3 (if you cannot access a computer, a paper version will be just as good)
Present your poster to your peers – speak to your teacher on how the group is going to do this, it might be a good idea to split into pairs and present to one another or set up a mini conference style poster session.

Tips

- Only use a small amount of text
- Use lots of colour, images, graphs and diagrams
- Make sure the text is in a clear font and is large enough to read while standing back from the poster

Part 3 – Study Skills, Tips & Guidance

This section includes helpful tips to help you complete this pack, as well as improve your study skills for any courses you take next year.

It also includes a few fantastic easy-to-use resources to know what to do next if you are hoping to go to university in the next few years, like UCAS advice and web links to more academic opportunities.

In this section:

University Study Skills:

- ✓ Cornell Notes
- ✓ Key Instruction Words
- ✓ Academic Writing
- ✓ Referencing
- ✓ Evaluating Your Sources

University Guidance:

- ✓ What next?

Subject Guidance:

- ✓ More on studying your subject

University Study Skills
Cornell Notes

University Ready

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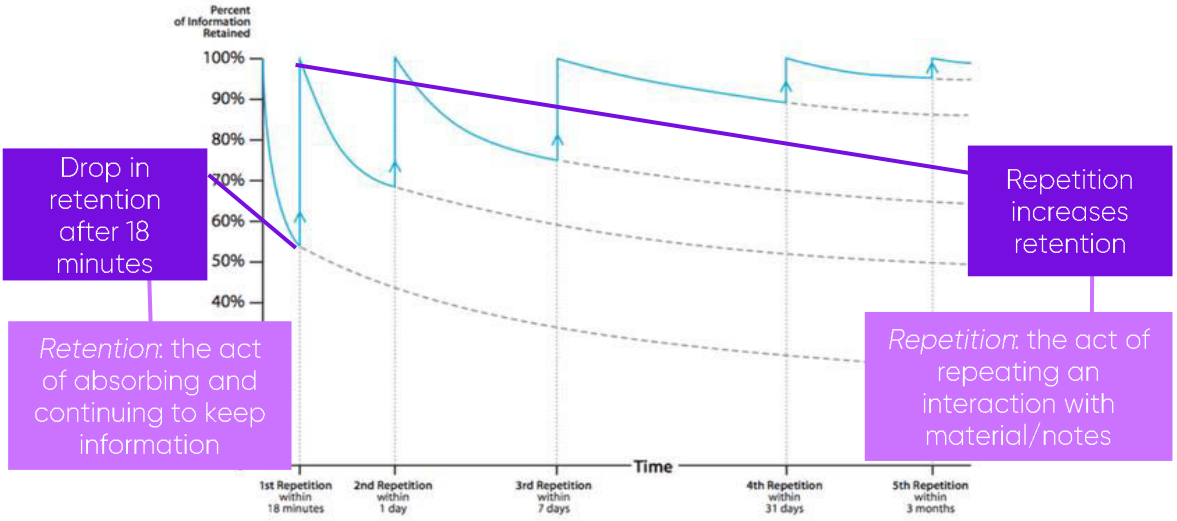
Why is good note-taking important?

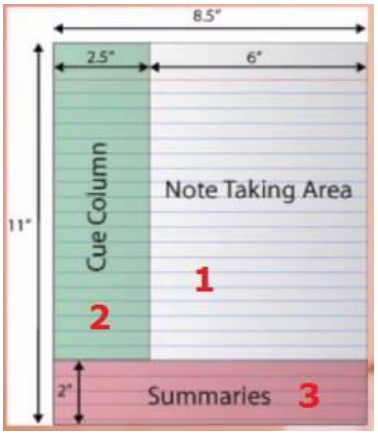
If it feels like you forget new information almost as quickly as you hear it, even if you write it down, that's because we tend to lose almost 40% of new information within the first 24 hours of first reading or hearing it.

If we take notes effectively, however, we can retain and retrieve almost 100% of the information we receive. Consider this graph on the rate of forgetting with study/repetition:



Learning a new system

The Cornell Note System was developed in the 1950s at the University of Cornell in the USA. The system includes interacting with your notes and is suitable for all subjects. There are three steps to the Cornell Note System.



Step 1: Note-Taking

1. Create Format: Notes are set up in the Cornell Way. This means creating 3 boxes like the ones on the left. You should put your name, date and topic at the top of the page.

2. Write and Organise: You then take your notes in the 'note taking' area on the right hand side of the page. You should organise these notes by keeping a line or a space between 'chunks'/main ideas of information. You can also use bullet points for lists of information to help organise your notes.

University Study Skills
Cornell Notes

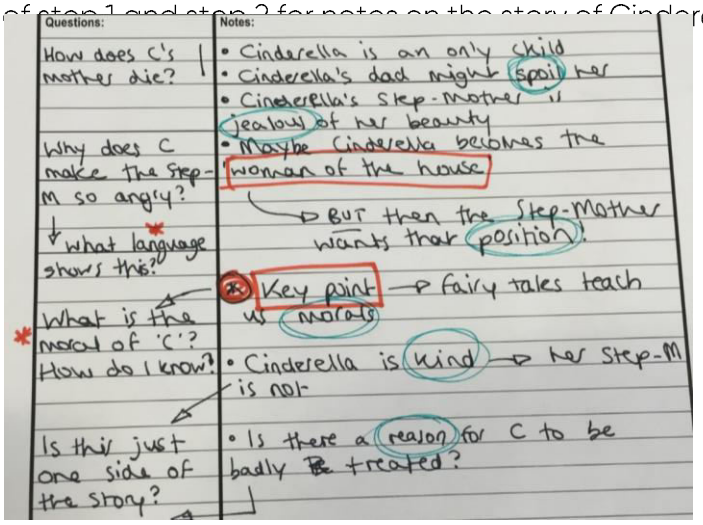
Step 2: Note-Making

1. Revise and Edit Notes: Go back to box 1, the note-taking area and spend some time revising and editing. You can do this by: highlighting 'chunks' of information with a number or a colour; circling all key words in a different colour; highlighting main ideas; adding new information in another colour.

2. Note Key Idea: Go to box 2 on the left hand side of the page and develop some questions about the main ideas in your notes. The questions should be 'high level'. This means they should encourage you to think deeper about the ideas. Example 'high level' questions would be:

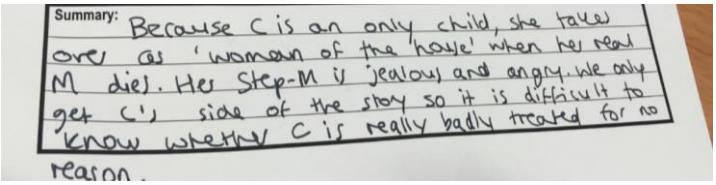
- Which is the most important/significant reason for...
- To what extent...
- How does the (data/text/ideas) support the viewpoint?
- How do we know that...

Here is an example of step 1 and step 2 for notes on the story of Cinderella:



Step 3: Note-Interacting

Summary: Go to box 3 at the bottom of the page and summarise the main ideas in box 1 and answer the essential questions in box 2.



Give the Cornell Note Taking System a try and see if it works for you!

University Study Skills
Key Instruction Words

These words will often be used when university tutors set you essay questions - it is a good idea to carefully read instruction words before attempting to answer the question.

Analyse – When you analyse something, you consider it carefully and in detail in order to understand and explain it. To analyse, identify the main parts or ideas of a subject and examine or interpret the connections between them.

Comment – When you comment on a subject or the ideas in a subject, you say something that gives your opinion about it or an explanation for it.

Compare – To compare things means to point out the differences or similarities between them. A comparison essay would involve examining qualities/characteristics of a subject and emphasising the similarities and differences.

Contrast – When you contrast two subjects, you show how they differ when compared with each other. A contrast essay should emphasise striking differences between two elements.

Compare and contrast – To write a compare and contrast essay, you would examine the similarities and differences between two subjects.

Criticise – When you criticise, you make judgments about a subject after thinking about it carefully and deeply. Express your judgement with respect to the correctness or merit of the factors under consideration. Give the results of your own analysis and discuss the limitations and contributions of the factors in question. Support your judgement with evidence.

Define – When you define something, you show, describe, or state clearly what it is and what it is like. You can also say what its limits are. Do not include details but do include what distinguishes it from the other related things, sometimes by giving examples.

Describe – To describe in an essay requires you to give a detailed account of characteristics, properties or qualities of a subject.

Discuss – To discuss in an essay, consider your subject from different points of view. Examine, analyse and present considerations for and against the problem or statement.

University Study Skills
Key Instruction Words

University Ready

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Continued

Evaluate – When you evaluate in an essay, decide on your subject's significance, value or quality after carefully studying its good and bad features. Use authoritative (e.g. from established authors or theorists in the field) and, to some extent, personal appraisal of both contributions and limitations of the subject. Similar to **assess**.

Illustrate – If asked to illustrate in an essay, explain the points that you are making clearly by using examples, diagrams, statistics etc.

Interpret – In an essay that requires you to interpret, you should translate, solve, give examples, or comment upon the subject and evaluate it in terms of your judgement or reaction. In other words, give an explanation of what your subject means. Similar to **explain**.

Justify – When asked to justify a statement in an essay, you should provide the reasons and grounds for the conclusions you draw from the statement. Present your evidence in a form that will convince your reader.

Outline – Outlining requires that you explain ideas, plans, or theories in a general way, without giving all the details. Organise and systematically describe the main points or general principles. Use essential supplementary material but omit minor details.

Prove – When proving a statement, experiment or theory in an essay, you must confirm or verify it. You are expected to evaluate the material and present experimental evidence and/or logical argument.

Relate – To relate two things, you should state or claim the connection or link between them. Show the relationship by emphasising these connections and associations.

Review – When you review, critically examine, analyse and comment on the major points of a subject in an organised manner

University Study Skills
Academic Writing

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What is academic writing?

'Academic writing' is a special way of writing when talking about research or a point of view.

It has a logical structure and uses formal language. Various sources of information are also used to support what is being said.

Academic writing: how to guide

- Use words you know and are confident using, making sure that what you write makes sense and is clear.
- Do not use contractions, like 'don't' or 'can't'. Instead, write these out fully: 'do not', 'cannot'.
- Do not use colloquialisms, meaning words or phrases that are not formal and that you would use when you speak. Examples include 'ace', 'brilliant', 'like chalk and cheese', etc.
- Do not use slang or jargon, for example 'daft', 'bloke', 'dodgy'.

Expressing your opinion in academic writing

In academic writing, it is best to express an opinion without writing in the first person. Your work should show that it is supported by specific evidence and facts, rather than your personal intuition.

Therefore, rather than saying 'In my opinion, this proves that', you can express the outcome of your reasoning in other ways:

- 'This indicates that…';
- 'The aforementioned problems in Smith's argument reveal that…';
- 'Such weaknesses ultimately mean that…', and so on.

Signposting

Signposting guides your reader through different sections of your writing. It tells them what is being discussed and why, and when your piece is moving from one part to another. It links ideas together and helps with the flow of your writing. Below are some examples of using signposting to:

- Expand on a previous idea:
  - 'Building on from the idea that…' (mention previous idea), 'this section illustrates that…' (introduce your new idea).
  - 'To further understand the role of…' (your topic/previous idea) this section explores the idea that… (introduce your new idea).

- Present a contrasting view:
  - 'However, another angle in this debate suggests that… (introduce your contrasting idea)
  - 'However, not all research shows that…' (mention your previous idea). 'Some evidence agrees that…'

University Study Skills
Referencing

University Ready

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What is a reference or referencing?

A reference is just a note in your assignment that tells your reader where specific ideas, information or opinions that you have used from another source have come from. It can be done through 'citations' or a 'bibliography'.

When you get to university, you will need to include references in the assignments that you write. As well as being academic good practice, referencing is very important, because it will help you to avoid plagiarism.

Plagiarism is when you take someone else's work or ideas and pass them off as your own. **Whether plagiarism is deliberate or accidental, the consequences can be severe.** You must be careful to reference your sources correctly.

Why should I reference?

Referencing is important in your work for the following reasons:

- It gives credit to the authors of any sources you have referred to or been influenced by.
- It supports the arguments you make in your assignments.
- It demonstrates the variety of sources you have used.
- It helps to prevent you from losing marks, or failing, due to plagiarism.

When should I use a reference?

You should use a reference when you:

- Quote directly from another source.
- Summarise or rephrase another piece of work.
- Include a specific statistic or fact from a source.

University Study Skills
Referencing

Is it a source worth citing?

Question your sources before referencing using these tips:

Currency: the timelines of the information

- When was it published or posted? Has it been revised or updated? Does your topic require current information, or will older sources work as well?

Relevance: the importance of the information for your needs

- Does the information relate to your topic or answer your question? Who is the intended audience? Have you looked at a variety of sources?

Authority: the source of the information

- Who is the author/publisher/source/sponsor? What are the author's credentials? Is the author qualified to write on the topic?

Accuracy: the reliability and correctness of the source

- Is the information supported by evidence? Has the information been reviewed or refereed? Can you verify whether it is a personal or professional source? Are there errors?

Purpose: the reason the information exists

- Does the author make their intentions/purpose clear? Is the information fact, opinion or propaganda? Are there are biases? Does the viewpoint appear objective?

University Study Skills
Referencing

University Ready

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How do I reference?

There is a number of different ways of referencing. However, most universities use what is called the Harvard Referencing Style. Talk to your tutor about which style they want you to use - the most important thing is that you remain consistent!

The two main aspects of referencing you need to be aware of are:

1. In-text citations

These are used when directly quoting a source. They should be located in the body of your work, after you have referred to your source in your writing. They contain the surname of the author of the source and the year it was published in brackets.

Example: *Daisy describes her hopes for her infant daughter, stating "I hope she'll be a fool – that's the best thing a girl can be in this world, a beautiful little fool."* ***(Fitzgerald, 2004).***

2. Bibliography

This is a list of all the sources you have referenced in your assignment. In the bibliography, you list your references by the numbers you have used and include as much information as you have about the reference. The list below gives what should be included for different sources.

- Websites – Author (if possible), *'title of the web page'*, 'Available at:' website address, [Accessed: date you accessed it].

  Example: *'How did so many soldiers survive the trenches?'*, Available at: http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [Accessed: 11 July 2019].

- Books – Author surname, author first initial, (year published), *title of book*, publisher

  Example: Dubner S. and Levitt, S., (2007), *Freakonomics: A Rogue Economist Explores the Hidden Side of Everything*, Penguin Books

- Articles – Author, *'title of the article'*, where the article comes from (newspaper, journal etc.), date of the article.

  Example: Maev Kennedy, *'The lights to go out across the UK to mark First World War's centenary'*, The Guardian Newspaper, 10 July 2014.

University Study Skills
Evaluating your sources

University Ready

Knowing about the different types of sources and what makes them worth using is important for academic work.

When doing research you will come across a lot of information from different types of sources. How do you decide which source to use? From newspaper articles to books to tweets, this provides a brief description of each type of source, and breaks down things to consider when selecting a source.

tweets

A platform for millions of very short messages on a variety of topics.

blogs

Blogs (e.g. Tumbler) are used for sharing both developed and unpublished ideas and interests with a niche community.

YouTube

A collection of millions of educational, inspirational, eye-opening and entertaining videos.

Newspaper

A reporting and recording of cultural and political happenings that keep the general public informed. Opinions and public commentaries can also be included.

Journals

A collection of analytics reports that outline the objectives, background, methods, results and limitations of new research written for and by scholars in a niche field.

Academic book

The information presented is supported by clearly identified sources. Sometimes each chapter has a different author.

Encyclopaedia

Books or online – giving information on many different subjects. Some are intended as an entry point into research, some provide detailed information and onwards references.

Popular book

A glossy compilation of stories with unique themes intended for specific interests.

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Evaluating your sources

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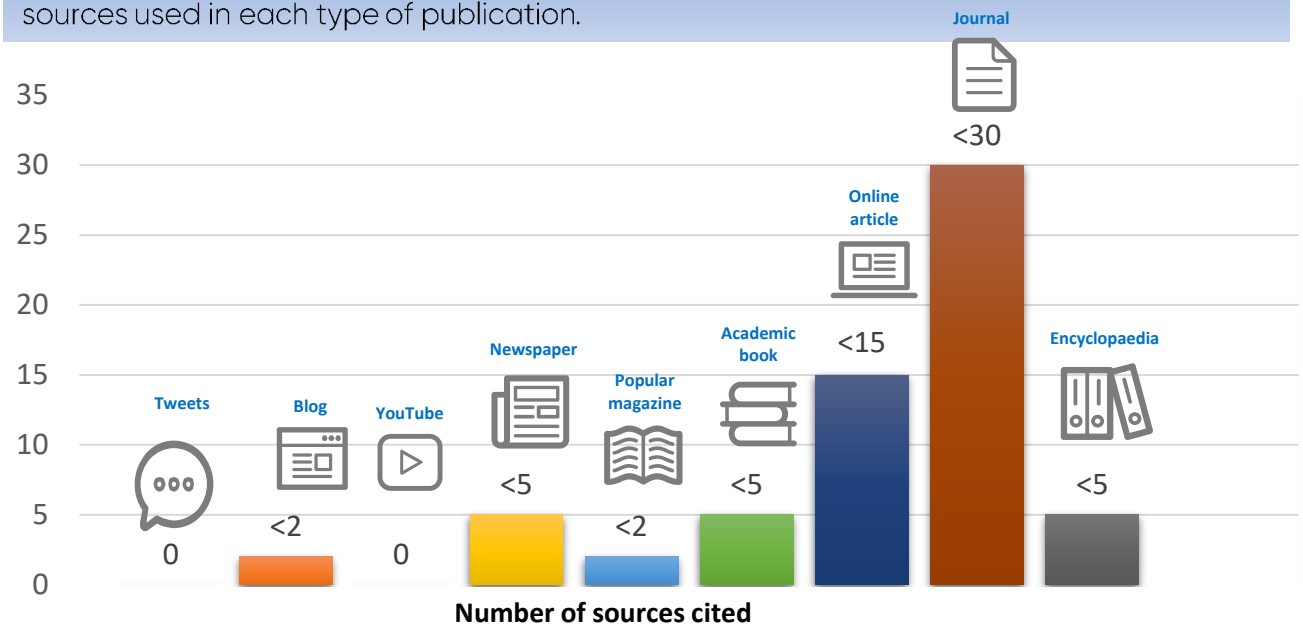
Number of outside sources

When an author used many outside sources in their writing, they demonstrate familiarity with ideas beyond their own. As more unique viewpoints are pulled into a source, it becomes more comprehensive and reliable. This shows the typical number of outside sources used in each type of publication.



Degree of review before a source is published

Two factors contribute to the amount of inspection that a source receives before it might be published: the number of reviewers fact-checking the written ideas, and the total time spent by reviewers as they fact-check. The more people involved in the review process and the longer the review process takes, the more credible the source is likely to be.

Number of reviewers			
Time in review			
0 reviewers			
	seconds	minutes	minutes
1-2 reviewers			
	hours	days	days
3-4 reviewers			
	2-3 months	6-12 months	3-5 years

University Guidance
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University Guidance

Different people go to university for different reasons. You might have a particular job in mind or just want to study a subject you are passionate about. Whatever your motivations, going to university can help improve your career prospects, as well as develop your confidence, independence and academic skills.

Choosing a course and university

Choosing the right course to study is an important decision so make sure you take time to research the different options available to you. Here are some top tips:

- ✓ You don't have to choose a course which you have already studied, there are lots of courses which don't require prior knowledge of the subject. You can apply skills gained from school studies to a new field.
- ✓ The same subject can be taught very differently depending on the course and university you choose. Take a look at university websites to find out more about the course content, teaching styles and types of assessment.
- ✓ When choosing a university, think about what other factors are important to you. Do you want to study at a campus university or be based in a city centre? What accommodation options are there? Does the university have facilities for any extracurricular activities you're involved in?
- ✓ To research your options, have a look at university leaflets and websites, and check if there are opportunities to speak to current students who can give you a real insight in to what life is like there.

MAKE HAPPEN

Take a look at the Make Happen website, makehappen.org/guides, for some really useful basic guides and videos on a range of subjects – from being the first in your family to go to university, to what it all costs, university life, where to live, and more! You can also follow us on Twitter @MakeHappenEssex, at //Facebook.com/MakeHappenEssex and on Instagram @makehappenessex.

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Exploring Careers and Subject Options

- ✓ Find job descriptions, salaries and hours, routes into different careers, and more at: https://www.startprofile.com/
- ✓ Research career and study choices, and see videos of those who have pursued various routes at: http://www.careerpilot.org.uk/
- ✓ See videos about what it's like to work in different jobs and for different organisations at: https://www.careersbox.co.uk/
- ✓ Find out where different degrees could lead to, how to choose the right course for you, and how to apply for courses and student finance at: https://www.prospects.ac.uk/
- ✓ Explore job descriptions and career options, and contact careers advisers at: https://nationalcareersservice.direct.gov.uk/
- ✓ Discover which subjects and qualifications (not just A-levels) lead to different degrees, and what careers these degrees can lead to at: http://www.russellgroup.ac.uk/media/5457/informed-choices-2016.pdf

Comparing Universities

Use our platform ThinkUni.org to take a short quiz about your preferences and interests to find out which universities might be a great fit for you.

Other popular resources:

https://www.ucas.com/

https://www.whatuni.com/

http://unistats.direct.gov.uk/

https://www.thecompleteuniversityguide.co.uk/

https://www.opendays.com/

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UCAS and the university application process

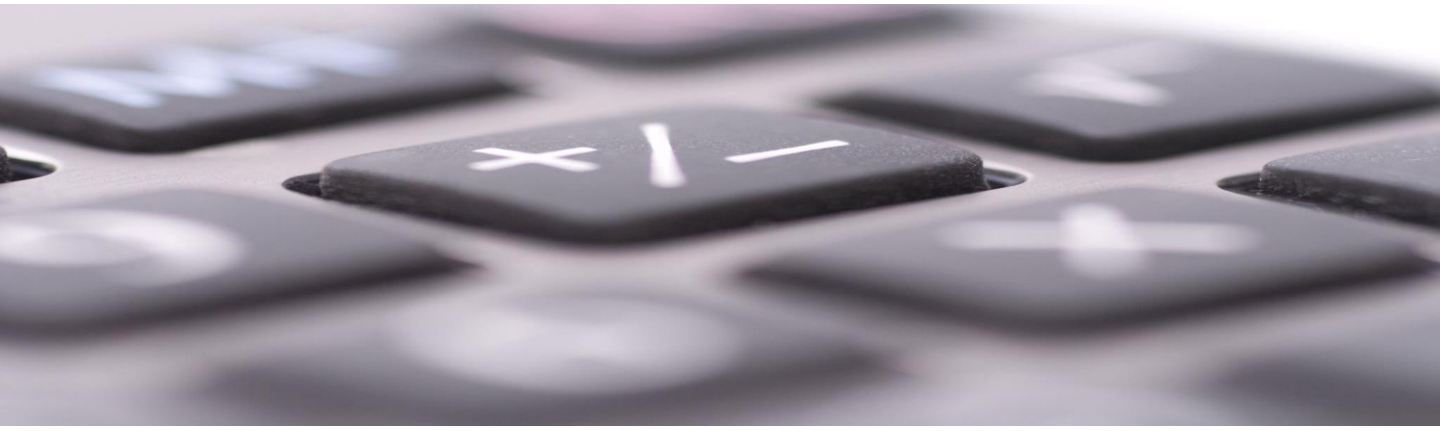
All applications for UK degree programmes are made through UCAS. There is lots of information on the UCAS website to guide you through the process and what you need to do at each stage.

These are the main steps you can expect:

- ✓ Applications **open in September** the year before you plan to start university.
- ✓ You can apply for up to **five courses.**
- ✓ The deadline for most courses is **15 January**, though there is an earlier deadline of **15 October** for Oxford and Cambridge, Medicine, Veterinary Medicine/Science and Dentistry.

- ✓ Some courses may require an interview, portfolio or admissions test in addition to the UCAS application. Check individual university websites for details.
- ✓ Check UCAS Track which will be updated with decisions from the universities you have applied for and to see your deadline for replying to any offers.
- ✓ You should choose a first and second choice university in case you don't get your first choice. If you already have your exam results or a university thinks your application is particularly strong, you might receive an **unconditional offer**.

- ✓ On the other hand, if you're holding a **conditional offer** then you will need to wait until you receive your exam results to have your place confirmed.
- ✓ Clearing & Adjustment allows you to apply to courses which still have vacancies if you didn't meet the conditions of your offer, have changed your mind about what or where you want to study, or have met and exceeded the conditions of your offer and would like to look at alternative options.



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Personal Statements

A really important part of your application is the Personal Statement. It gives you the opportunity to tell universities why they should offer you a place.

- ✓ You can only submit one Personal Statement so it's important that you are consistent in your course choices. Make sure you have done your research to show your understanding of the subject area and passion for it.
- ✓ Start by brainstorming all your skills, experience and attributes. Once you have everything written down, you can begin to be selective – you only have 47 lines so won't be able to include everything.

Here a few top tips for making your Personal Statement stand out:

- Explain why you want to study your chosen subject
- Say what area of your chosen subject fascinates you
- Demonstrate your interest by mentioning what you have recently read, watched or listened to, and how they helped your understanding of the subject
- Mention activities or practical work you have completed which helped to develop any subject-related skills
- Describe how your school or individual work has equipped you with the necessary knowledge and ability to be a successful student in that subject.

Useful resources

- ✓ Key dates and deadlines: www.access-ed.ngo/timelines-for-applying-to-university
- ✓ Get tutor advice on writing a UCAS personal statement at: www.access-ed.ngo/writing-your-ucas-personal-statement
- ✓ An easy template to start practising your personal statement: https://www.ucas.com/sites/default/files/ucas-personal-statement-worksheet.pdf
- ✓ Untangle UCAS terminology at: https://www.ucas.com/corporate/about-us/who-we-are/ucas-terms-explained
- ✓ Discover more about the application process including when to apply and how to fill in your application on the UCAS website.
- ✓ Read more useful advice about what to include in your personal statement on UCAS, the Complete University Guide and The Student Room.
- ✓ Attend one of our virtual sessions to find out more about applying and personal statements.

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Student Finance

Concerns about money should not be a barrier to accessing higher education. There are lots of different forms of financial support available to you, including government loans and grants, as well as a range of scholarships and bursaries.

Key facts to remember

- You do not have to pay tuition fees upfront. If you are eligible for funding through Student Finance authorities, which most students will be, then you can apply for a loan which covers the full tuition fee and is paid directly to universities.
- You can also apply for a living cost loan to help with costs such as accommodation, travel and food. How much you receive will depend on your household income and where you choose to live and study.
- Repayments don't start until the April after you finish or leave your course and only if your income is over the repayment threshold. The amount you repay is based on your income, not how much you borrow, and any outstanding amount is written off after 30 years.
- There are additional forms of support available depending on your individual circumstances including Disabled Students' Allowances and grants for students with adult or child dependants. These grants do not normally have to be repaid.
- Universities and other organisations will also offer bursaries, scholarships and other forms of financial support so make sure you research all the funding available to you.

Useful resources

✓ Get the key facts and figures about Student Finance from: https://www.gov.uk/student-finance.

✓ Check how much you could be eligible to receive using the Student Finance Calculator.

✓ Find out more about Student Finance England support on the Student Room's Finance Zone.

✓ Check your money ready for university with this online course.

More on studying this subject

A Deeper Look Into Chemistry

- ✓ **Read:** Articles published by Chemistry World magazine
  https://www.chemistryworld.com/

- ✓ **Watch:** The Royal Society of Chemistry Christmas lectures
  https://www.rigb.org/christmas-lectures/watch

- ✓ **Listen:** To the Chemistry World podcasts
  https://www.chemistryworld.com/podcasts

- ✓ **Do:** Check out the Diamond Light Source Synchrotron facilities for some amazing and super powerful characterisation techniques
  https://www.diamond.ac.uk/Public/For-School.html

www.researchbasedcurricula.com

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