OVERVIEW

Resource Pack AccessEd Research-Based Curricula
Biochemistry Key Stage 4
www.researchbasedcurricula.com

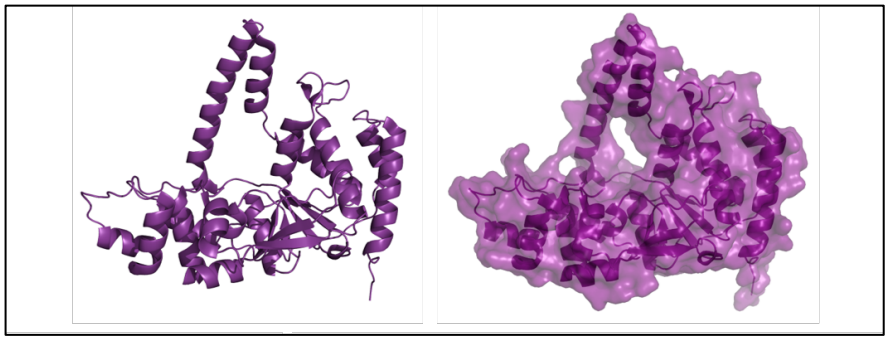
The Biochemical Characterisation of Flap Endonuclease 1 (FEN1)

AGE
14-16
Year 10
Year 11

CURRICULUM
B
Biochemistry

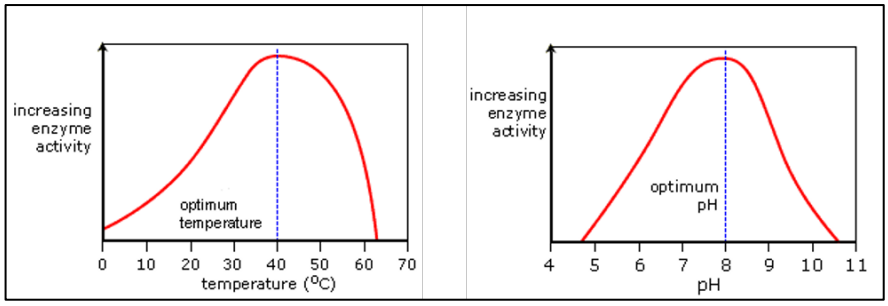
OFQUAL
AO1
AO2
AO3
Assessment Objectives

CONTENTS
6 Resources
Teacher Notes
Subject IAG



M-G-I-Q-G-L-A-K-L-I-A-D-V-A-P-S-A-I-R-E-….

First Letter	Second Letter: T	Second Letter: C	Second Letter: A	Second Letter: G	Third Letter
T	TTT Phenylalanine (F)	TCT Serine (S)	TAT Tyrosine (Y)	TGT Cysteine (C)	T
	TTC Phenylalanine (F)	TCC Serine (S)	TAC Tyrosine (Y)	TGC Cysteine (C)	C
	TTA Leucine (L)	TCA Serine (S)	TAA STOP	TGA STOP	A
	TTG Leucine (L)	TCG Serine (S)	TAG STOP	TGG Tryptophan (W)	G
C	CTT Leucine (L)	CCT Proline (P)	CAT Histidine (H)	CGT Arginine (R)	T
	CTC Leucine (L)	CCC Proline (P)	CAC Histidine (H)	CGC Arginine (R)	C
	CTA Leucine (L)	CCA Proline (P)	CAA Glutamine (Q)	CGA Arginine (R)	A
	CTG Leucine (L)	CCG Proline (P)	CAG Glutamine (Q)	CGG Arginine (R)	G
A	ATT Isoleucine (I)	ACT Threonine (T)	AAT Asparagine (N)	AGT Serine (S)	T
	ATC Isoleucine (I)	ACC Threonine (T)	AAC Asparagine (N)	AGC Serine (S)	C
	ATA Isoleucine (I)	ACA Threonine (T)	AAA Lysine (K)	AGA Arginine (R)	A
	ATG Methionine (M)	ACG Threonine (T)	AAG Lysine (K)	AGG Arginine (R)	G
G	GTT Valine (V)	GCT Alanine (A)	GAT Aspartic Acid (D)	GGT Glycine (G)	T
	GTC Valine (V)	GCC Alanine (A)	GAC Aspartic Acid (D)	GGC Glycine (G)	C
	GTA Valine (V)	GCA Alanine (A)	GAA Glutamic Acid (E)	GGA Glycine (G)	A
	GTG Valine (V)	GCG Alanine (A)	GAG Glutamic Acid (E)	GGG Glycine (G)	G



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Office for Students

Contents

PART 1: INTRODUCTION

Welcome!

To get into the best universities, you must demonstrate that you are intellectually curious, and will make the most of the wonderful academic opportunities available to you.

One of the best ways of demonstrating this, is by going above and beyond what is taught in school and studying something that is not on the curriculum.

This resource will give you exactly such an opportunity. You will have something interesting to write about in your application to university, something interesting to talk about in a university interview, and open whole new areas of study you might be interested in!

You will develop valuable academic skills as you go, that we have marked out with gold badges (see the next page on university skills). As you work through the resource you can look out for these badges so that you can explain which skills you have developed and what you did to demonstrate them. Developing these skills will help you get university ready!

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!

I am a historian and as a university student I became interested in the history of science. In fact, my curiosity took me to the University of Wisconsin in the USA where I studied in the history of science, medicine and technology programme. Did you know that scientists once believed that living things could spontaneously generate? That means life could form without other life or a parent. I recommend researching the history of physics using Google Books.
Dr Rajbir Hazelwood Programme Director, AccessEd

I love listening to podcasts, and I highly recommend listening to weekly podcasts as it's a quick and interesting way to discover new ideas and hear experts speak about what they know best. I would recommend finding new episodes on nature.com that excite you. You could find out more about coral reefs, brain scans or electric sheep!
Michael Slavinsky Education Director, The Brilliant Club

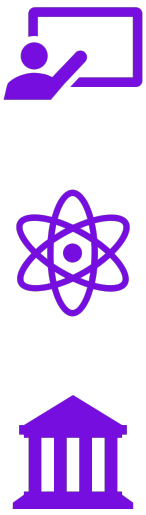
University Skills

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 of 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 that 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 that 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.

Here are the skills that you will develop in this course:

independent research	your ability to work on your own and find answers online or in other books
creativity	your ability to write something original and express your ideas
problem solving	your ability to apply what you know to new problems and challenges
building an argument	your ability to logically express yourself
providing evidence	your ability to refer to sources that back up your opinions and 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 for bias, origin, purpose and utility
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

INFORMATION FOR TEACHERS



AIMS

The Research-Based Curricula Programme creates classroom resources that are based on cutting-edge academic expertise at local universities.

These resources are intended to encourage pupils to broaden their understanding of subjects and expose them to academic research, as well as supporting the development of core academic skills that boost exam attainment.

Teachers can use these resources to supplement activities in existing lessons, to design new lessons, or to stretch and challenge high-achieving pupils with extension work.

The aim of the programme is to support pupils to develop cognitive and non-cognitive skills that the research shows supports progression to university. This includes deep subject knowledge, critical thinking, and written and verbal communication.

EVIDENCE

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 of which is 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.

The Brilliant Club

Achievement for All
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Department for Education

TEACHERS

The Research-Based Curriculum is designed to be used flexibly by teachers to tailor extension activities for their students. Some teachers may choose to adapt the resources for groups of students during lessons.

The resources are designed to be completed individually or in small groups, so teachers can use them as class-based or homework tasks. Equally, teachers can give the pack to some students to work through independently when they have finished their normal class work or during an extra-curricular club.

The resources will challenge students to think deeply about specific content that may be beyond the confines of the exam curriculum, while informing them about cutting-edge research being carried out at local universities. All the resources can help develop specific skills required for GCSE examinations, which are referenced in the Teacher Notes throughout the pack.

PARTNERS

AccessEd is a non-profit organisation that works to increase university access for under-represented young people globally. We work in partnership with universities and schools to deliver programmes that mobilise researchers to share their academic expertise with young people and the public. Visit www.access-ed.ngo. Follow @_AccessEd

The Higher Education Progression Partnership South Yorkshire plus (HeppSY+) is part of a national programme to help school and college students aged 13-19 in South Yorkshire, who are most at risk of missing out on higher education. HeppSY+ is working in partnership with Sheffield Hallam University, the University of Sheffield, and South Yorkshire colleges and schools. Visit www.heppsy.org. Follow @HeppSYplus

The Biochemical Characterisation of Flap Endonuclease 1 (FEN1)

Deep Dive

Biochemistry is an important scientific area which bridges the gap between biology and chemistry. Researchers who work in this field seek to discover how different molecules (such as DNA and proteins) work in living organisms (including bacteria, yeast, humans and plants). Biochemistry research can offer insights into how crop plants can be made to grow more efficiently in tough conditions, helping to feed people across the world who struggle to grow enough food to eat. It can also help discover how the DNA in our cells is replicated and how it is repaired when things go wrong, research like this is vital in the hunt for new ways to treat diseases like cancer.

Understanding the intricate workings of molecules such as DNA or proteins, and the chemical reactions in which they are involved, requires an understanding of topics covered in both biology and chemistry at GCSE and A level. While the techniques and technology used to uncover this information may be sophisticated, data obtained would mean nothing without an understanding of topics such as protein structure or reaction kinetics. An ability to interpret experimental data and apply it to your knowledge of the molecule(s) you are studying is crucial to link information together. Studying biochemistry allows a unique insight into the crossover between the subjects of biology and chemistry, making it a fantastic area to study.

In this resource pack, you will uncover the details of protein and DNA structure, the ways that enzymes act as catalysts in biological systems, and how electrolysis can be used in research to answer important questions. You will also have the opportunity to examine the rates of reaction of a real enzyme that is involved in DNA replication and present in every cell of your body.

Active Reading

Highlight key words or new vocabulary

Introduction to Studying Biochemistry at University

Biochemistry is the study of the chemical reactions occurring in living organisms. It is a subject which bridges the more traditional areas of chemistry and biology, allowing scientists to study topics which fit somewhere between these two. This ability to link the subjects of chemistry and biology means that biochemistry is what is known as an interdisciplinary subject.

The study of biochemistry and other subjects related to it such as molecular biology, genetics, biology, chemistry and biomedical sciences (to name a few) allow scientists to unlock the secrets of a wide variety of organisms (including bacteria, yeast, plants and humans) which may then be utilised in society. Historically, this has led to the development of medicines such as antibiotics and to advances in forensic science like DNA fingerprinting. Understanding the chemical reactions which are occurring in living things can allow researchers to develop crops which grow more efficiently in tough conditions. It can also help increase the understanding of diseases such as cancer and lead to the development of better treatments for them. Recent advances in biochemistry have included a compound which can increase immunity to cancer, a new antibiotic thought to be able to treat antibiotics resistant 'superbugs', an app to help scientists understand how hay fever is triggered and a new technique using tiny gold nanoparticles to study individual molecules.

I hope as you start to learn a little about biochemistry from studying these six topics that you will start to appreciate the incredible molecules which form so much of the life you see around you and that you will start to appreciate how simple experiments can answer some very important scientific questions for researchers such as myself. These topics may seem tricky at first, but I hope that as you study them you will discover than you can understand more than you thought and that you enjoy learning a bit of biochemistry.

Good luck!
Rebecca Ley

Meet the PhD Researcher: Rebecca Ley

After studying for A levels in Biology, Chemistry, Maths and Further Maths, I arrived at the University of Sheffield in September 2009 excited to begin studying to become a doctor. Two years later, having learnt a lot of interesting medical science and completed my first hospital placement, I realised that a medical degree was not the right one for me and decided to change course. In September 2011 I started a Chemistry degree and four years later I graduated with a master's degree in chemistry. Later in 2015 I started my PhD research, investigating an enzyme (called Flap Endonuclease 1, or FEN1) which is crucial for DNA replication.

My research specifically aims to investigate how this enzyme (which cuts DNA very efficiently) is controlled so it is only active and cutting DNA when required. This is an important research area as changes in the activity of FEN1 are implicated in a wide variety of cancers.

A-Level Subjects: Biology, Chemistry, Maths and Further Maths

Undergraduate: Chemistry

Postgraduate: Chemistry

What is a PhD student? A PhD, or Doctor of Philosophy is the highest academic qualification awarded by most universities. PhD students conduct original research on a specific topic or question, producing a thesis that is typically 70,000 - 100,000 words long and defending their thesis to experts in their chosen field to obtain a PhD.

What is a PhD researcher? A PhD researcher, or post-doctoral researcher has already obtained their PhD qualification and has continued to work in their chosen field or a similar field.

What is a university department? A university department is a group of academics working in a similar area of interest including professors, lecturers, principal investigators (PIs), post-doctoral researchers, PhD students, masters and undergraduate students.

Did you know?

Sheffield University has a new multi-million pound electron microscope, opened by Dr Richard Henderson (Noble Prize in Chemistry 2017_. Electron microscopes can look at tiny microorganisms, cells, crystals and even some large molecules.

PART 2: RESOURCES

Resource Pack AccessEd Research-Based Curricula
Biochemistry Key Stage 4
www.researchbasedcurricula.com

Proteins – From Building Blocks to Intricate Structures

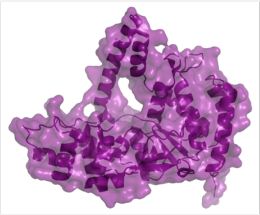
Link to curriculum
Amino Acids, Proteins, Polymers

TEACHER NOTE

For GCSE Additional Science students should be enabled to:

- Use scientific vocabulary, terminology and definitions.
- Translate from data to a representation with a model.
- Use models in explanations, or match features of a model to the data from experiments or observations that the model describes or explains.
- Presenting observations and other data using appropriate methods.
- Interpreting observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.

INSTRUCTIONS



1. Read and annotate the data source
2. Complete the written activities
3. Explore the further reading
4. Move on to Resource 2 in this pack

CONTEXT

Proteins are large biomolecules which are formed from long chains of amino acids. The sequence of amino acids in these chains determines the overall 3D structure of the proteins and this in turn influences the role played by an individual protein in an organism.

Knowing the overall structure of a protein can give scientists an insight into the role of particular regions or amino acids in the function of the protein. Scientists use a technique called x-ray crystallography to take pictures of protein molecules which have been made into crystals from a solution.

Data Source

The box below shows the structures of three different proteins (in different colours) which have been determined using x-ray crystallography. For each protein you can see two different types of image. Those on the left-hand side show the structure of the protein backbone to give scientists information about the different secondary structures present (keep reading for more information on secondary structure). The images on the right-hand side show the full surface of the protein over the top of the image on the left. Unlike the images on the left, those on the right take into account all the atoms present in the protein and include the amino acid side chains as well as the protein backbone. In purple you can see Flap Endonuclease 1 (FEN1), a protein which plays a key role in DNA replication; Green Fluorescent Protein (GFP) which is found in bioluminescent jellyfish is shown in green; and in blue is insulin, a hormone which regulates blood sugar levels in cells. As you can see, they all have unique shapes, with the GFP forming a barrel-shaped structure, and insulin being a dimer formed from two identical protein subunits.

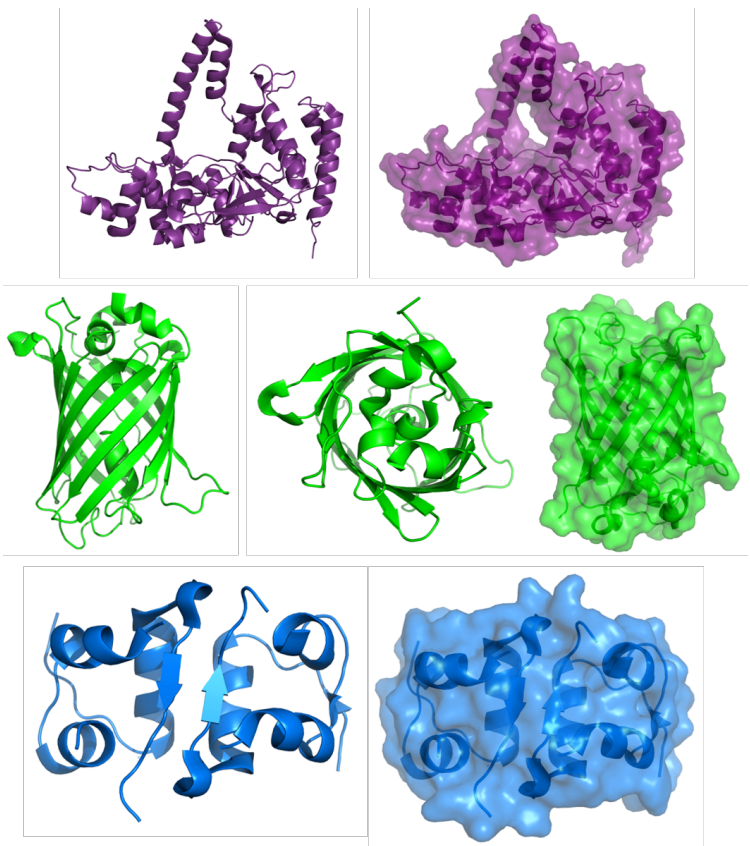


Figure 1. X-ray crystallography images of Flap Endonuclease 1 (FEN1) (purple), Green Fluorescent Protein (GFP) (green) and insulin (blue)

Data Source (continued...)

The overall 3D structure of a protein is determined by its amino acid sequence. Individual amino acids bond together forming a chain like the beads on a necklace. These chains can be hundreds of amino acids long, for example human FEN1 has a sequence which is 380 amino acids long, the first 20 of which are shown in the image below. This is known as the primary structure of a protein.

M-G-I-Q-G-L-A-K-L-I-A-D-V-A-P-S-A-I-R-E-….

Figure 2. The first 20 amino acids in the FEN1 protein sequence

A chain of amino acids can fold up to form recognisable secondary structures. The most common of these are alpha helices which form regular spirals, and beta sheets which are flat structures formed between adjacent chains of amino acids.

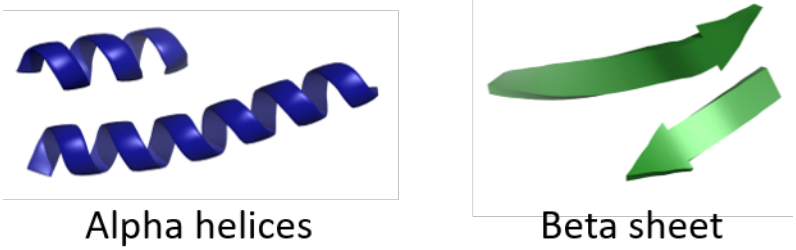


Figure 3. Secondary structures of a protein

The final step in the structuring of a protein is the folding of the chain into its overall 3D shape, known as its tertiary structure. Some proteins have a quaternary structure which may involve multiple amino acid chains folding together to form the final structure, or the organisation of an amino acid chain around metal ions. FEN1 has a quaternary structure, with 3 metal ions involved in the formation of its final structure.

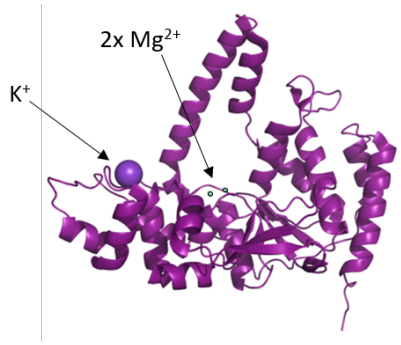


Figure 4. Quaternary structure of FEN1 protein

Activity 1

Sometimes it is very useful for scientists to examine the whole sequence of amino acids for a protein. The protein I work on, human FEN1, has a sequence of 380 amino acids. Writing this out with the full names of the amino acids is not practical, so scientists convert the names of amino acids into a three-letter and single-letter code to make it easier.

Using the table below, write out the three- and single-letter codes for the amino acid sequence written.

Amino Acid	Three-letter code	Single-letter code
Isoleucine	Ile	I
Leucine	Leu	L
Valine	Val	V
Phenylalanine	Phe	F
Methionine	Met	M
Cysteine	Cys	C
Alanine	Ala	A
Glycine	Gly	G
Proline	Pro	P
Threonine	Thr	T
Serine	Ser	S
Tyrosine	Tyr	Y
Tryptophan	Trp	W
Glutamine	Gln	Q
Asparagine	Asn	N
Histidine	His	H
Glutamic Acid	Glu	E
Aspartic Acid	Asp	D
Lysine	Lys	K
Arginine	Arg	R

Cysteine--Histidine–Glutamic Acid--Methionine--Isoleucine--Serine--Threonine--Arginine--Tyrosine

Activity 2

Match the following words to their definition:

Amino acid	A sheet of connected amino acids, a type of secondary structure
Primary Structure	A type of secondary structure forming a regular spiral
Secondary Structure	Large molecules made from long chains of amino acids
Tertiary Structure	A linear sequence of amino acids encoded by DNA
Quaternary Structure	Organisation of an amino acid chain into regular shapes
Alpha Helix	Small structural units that make up proteins
Beta Sheet	The final 3D shape of a protein
Proteins	Metal ions or multiple amino acid chains incorporated into the final 3D shape of the protein

Activity 3

Write a paragraph to describe the structure of a protein, starting from the primary structure and building up to the final shape. Use the images provided in the introduction to help and be sure to include all the words you defined in activity 2.

Further Reading

DNA replication video (Part 2, from 1min 44seconds) - https://www.wehi.edu.au/wehi-tv/molecular-visualisations-dna (FEN1 is involved in lagging strand synthesis)

More detail on protein structure - https://en.wikipedia.org/wiki/Protein_structure (remember that Wikipedia is a great resource for background information but because it can be edited by anyone you should always check that what you are reading has references for the information – these can be found at the bottom of the page).

Research paper: Human Flap Endonuclease structures, DNA double-base flipping, and a unified understanding of the FEN1 superfamily (https://www.ncbi.nlm.nih.gov/pubmed/21496641) – some of this paper might be complicated to understand but it is the paper which first described the structure of human FEN1 with its product and substrate DNA.

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The Structure and Manipulation of DNA

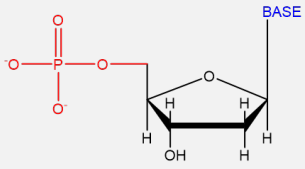
Link to curriculum
DNA, Genetic Engineering, Polymers

TEACHER NOTE

For GCSE Additional Science students should be enabled to:

- Interpreting observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.
- Translating data from one form to another.
- Presenting reasoned explanations including relating data to hypotheses.
- Communicating the scientific rationale for investigations, methods used, findings and reasoned conclusions through paper-based and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

INSTRUCTIONS



1. Read and annotate the data source
2. Complete the written activities
3. Explore the further reading
4. Move on to Resource 3 in this pack

CONTEXT

DNA Structure

DNA is the chemical molecule in the nucleus of cells which holds the genetic code. It is a polymer formed of two antiparallel chains of nucleotides which twist to form a shape called a double helix. The picture to the right shows a picture of part of a real DNA molecule produced using a technique called x-ray crystallography and shows the characteristic structure.

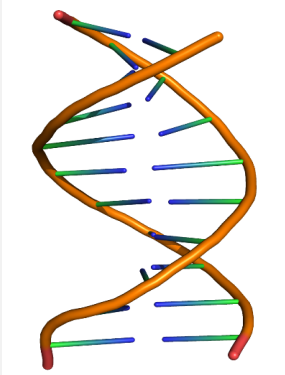


Figure 5. Part of a DNA molecule

Data Source

If you untwist the above structure and look at the bases which are along the backbone you would find a sequence of DNA nucleotide base pairs. It is thought there are more than 3 billion base pairs in the human genome and that 25,000 genes are contained within this sequence. Genes are small sections of DNA which code for a specific protein. In order to allow all this DNA to fit inside the nucleus of a cell, DNA is packaged up into 23 pairs of chromosomes tightly folded around proteins called histones.

A DNA nucleotide is made up from three main parts: a phosphate group (shown below in red), a deoxyribose sugar (in black) and one of four DNA bases (in blue). These are the building blocks of DNA with the phosphate group and sugar of neighbouring nucleotides linking together to form the DNA backbone. There are four DNA bases; adenine (A), cytosine (C), guanine (G) and thymine (T) which point into the middle of the DNA helix as seen above.

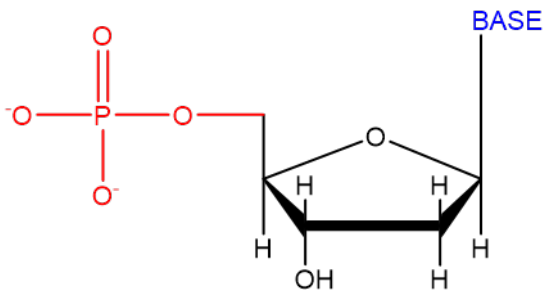


Figure 5. A phosphate group

Data Source (continued...)

Deep Dive

Genetic Engineering

Genetic engineering techniques are widely used in biochemistry research. These techniques allow scientists to manipulate DNA sequences which usually leads to a change in the sequence of the protein coded for by that DNA sequence. Often genetic engineering techniques use a reaction called the Polymerase Chain Reaction which allows scientists to amplify DNA sequences quickly and efficiently in a lab. In order to produce large amounts of protein in a lab, scientists use circular DNA structures called plasmids which they put into *E. coli* bacteria using the protein producing machinery of the bacterial cells to overexpress the protein. In my lab we use this technique to produce a human protein called Flap Endonuclease 1 (FEN1).

Plasmids which allow *E. coli* to produce a human enzyme such as FEN1 can be made using proteins called restriction enzymes which cut a DNA helix at specific sequences of DNA bases (like a pair of DNA scissors). Firstly, a circular DNA plasmid (commonly found in bacteria) is cut in two places using restriction enzymes as shown in the image below. This stops it being circular, allowing the DNA to open out into an open strand. The short piece of DNA which was cut out is now not needed. A new piece of DNA (shown in red on the image below) can then be ligated (stuck) into the DNA using an enzyme called DNA ligase, making a complete circle again. The now complete plasmid can be inserted into *E. coli* cells and used to overexpress FEN1.

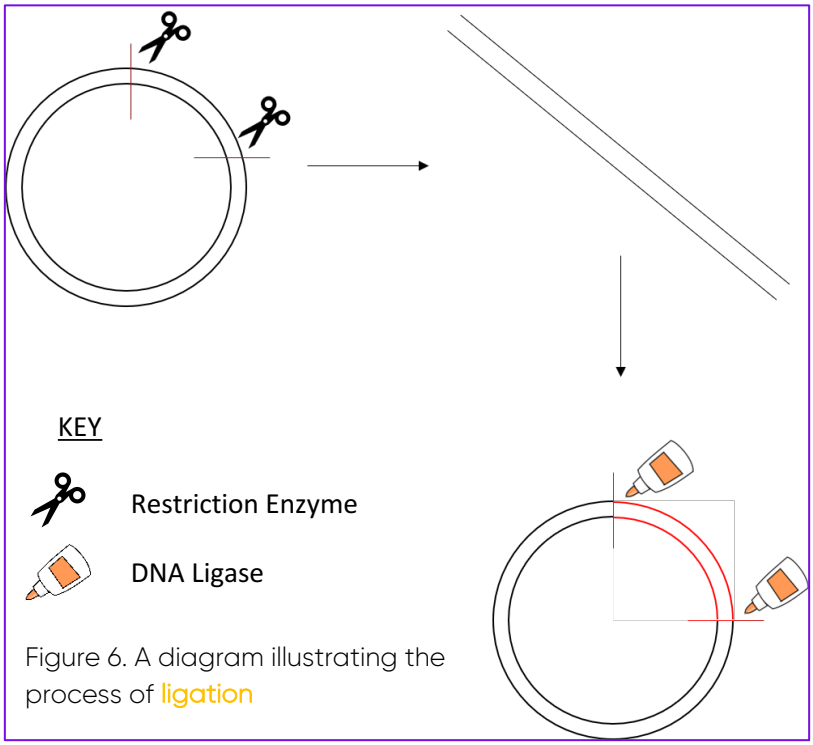
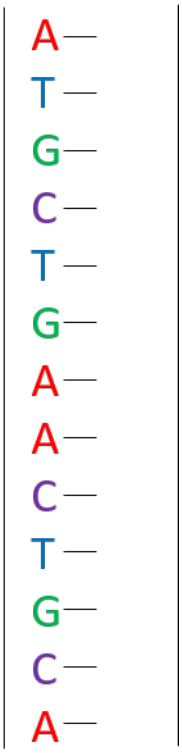


Figure 6. A diagram illustrating the process of ligation

Activity 1

The DNA bases on opposite strands of a DNA helix are arranged into pairs known as base pairs. These base pairs are complementary, which means A always binds to T, and C to G.

On the image below, fill in the complementary base pairs on the DNA where indicated.



Activity 2

Groups of 3 nucleotides (called codons) code for particular amino acids in a non-overlapping sequence. As shown in the table below, a number of different amino acids and stop codes are coded for by these codons.

First Letter	Second Letter: T		Second Letter: C		Second Letter: A		Second Letter: G		Third Letter
T	TTT	Phenylalanine (F)	TCT	Serine (S)	TAT	Tyrosine (Y)	TGT	Cysteine (C)	T
	TTC		TCC		TAC		TGC		C
	TTA	Leucine (L)	TCA		TAA	STOP	TGA	STOP	A
	TTG		TCG		TAG		TGG	Tryptophan (W)	G
C	CTT	Leucine (L)	CCT	Proline (P)	CAT	Histidine (H)	CGT	Arginine (R)	T
	CTC		CCC		CAC		CGC		C
	CTA		CCA		CAA	Glutamine (Q)	CGA		A
	CTG		CCG		CAG		CGG		G
A	ATT	Isoleucine (I)	ACT	Threonine (T)	AAT	Asparagine (N)	AGT	Serine (S)	T
	ATC		ACC		AAC		AGC		C
	ATA		ACA		AAA	Lysine (K)	AGA	Arginine (R)	A
	ATG	Methionine (M)	ACG		AAG		AGG		G
G	GTT	Valine (V)	GCT	Alanine (A)	GAT	Aspartic Acid (D)	GGT	Glycine (G)	T
	GTC		GCC		GAC		GGC		C
	GTA		GCA		GAA	Glutamic Acid (E)	GGA		A
	GTG		GCG		GAG		GGG		G

The DNA sequence coding for a protein will begin with a start codon ATG which codes for an amino acid called methionine and end with a STOP codon as seen in the table. The DNA sequence below codes for the first 20 amino acids of human Flap Endonuclease 1.

Using the table above, write the sequence of amino acids coded for by the nucleotide sequence. The first has been done for you:

ATG GGA ATT CAA GGC CTG GCC AAA CTA ATT GCT GAT GTG GCC CCC AGT GCC ATC CGG GAG
M

Mutations can occur in the genetic code and may change the sequence of amino acids which is coded for by a gene. There are three possible mutations which can occur:

1. Insertions – a DNA base is inserted into the sequence adding an extra base
2. Deletions – a DNA base is removed from the sequence
3. Substitutions – one DNA base is switched for another

With a partner discuss what effect these three different mutations might have on the above sequence of DNA and therefore the amino acid sequence which is coded for. Write down your answer - it may be helpful to include DNA sequences to help explain your thoughts.

Activity 3

Restriction enzymes are used by research scientists in genetic engineering experiments. These enzymes cut DNA at specific sequences known as restriction sites and can be used to cut a required sequence out of a long strand of DNA. DNA cut by restriction enzymes can either have blunt ends with both DNA strands cut at the same base pair, or sticky ends where the strands are cut at different positions to form an overhanging DNA sequence. A video showing the formation of sticky ends by EcoR1 can be found in the further reading. Below are six restriction enzymes and the DNA sequences they recognise and shown in red how they cut the DNA.

Using this information, mark on the DNA strands which restriction enzymes can cut them. (Hint: each can be cut by only 2)
Work out which strand could be inserted into which of the circular vectors below .

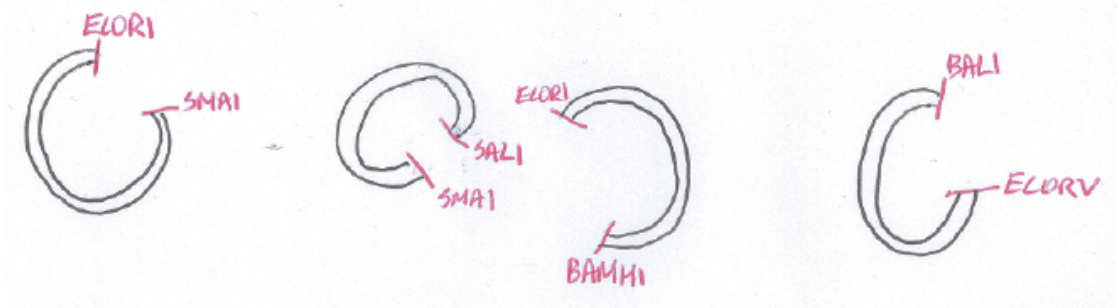
Data Interpretation

ECORI	5'-GAATTC-3' 3'-CTTAAG-5'	BALI	5'-TGGCCA-3' 3'-ACCGGT-5'
BAMHI	5'-GGATCC-3' 3'-CCTAGG-5'	SMAI	5'-CCCGGG-3' 3'-GGGCCC-5'
SALI	5'-GTCGAC-3' 3'-CAGCTG-5'	ECORV	5'-GATATC-3' 3'-CTATAG-5'

5'-ATTGAATTCGATGTAGCCCTTCAGGATCCTACG-3'
3'-TAACTTAAGCTACATCGGGAAGTCCTAGGATGC-5'

5'-ATGCGTCCCGGGTTAAGCTAGCTATGCGAATTCTGA-3'
3'-TACGCAGGGCCCAAYYCGATCGATACGCTTAAGACT-5'

5'-ATGTCTATGATATCGCTAGTACTAATGGCCATGAC-3'
3'-TACAGATACTATAGCGATCATGATTACCGGTACTG-5'



Further Reading

More detail on DNA structure - https://en.wikipedia.org/wiki/Nucleic_acid_structure (remember that Wikipedia is a great resource for background information but you should always check that what you are reading has references for the information – these can be found at the bottom of the page)

Protein synthesis video - https://www.youtube.com/watch?v=gG7uCskUOrA

Watch EcoR1 at work on DNA - https://www.wehi.edu.au/wehi-tv/restriction-enzyme-ecor1

Resource Pack AccessEd Research-Based Curricula
Biochemistry Key Stage 4
www.researchbasedcurricula.com

Biological Machines

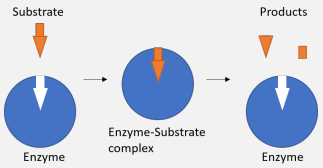
Link to curriculum
Enzymes, Catalysts

TEACHER NOTE

For GCSE Additional Science students should be enabled to:

- Presenting reasoned explanations including relating data to hypotheses.
- Communicating the scientific rationale for investigations, methods used, findings and reasoned conclusions through paper-based and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.
- Interpreting observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.
- Use scientific vocabulary, terminology and definitions.

INSTRUCTIONS



1. Read and annotate the data source
2. Complete the written activities
3. Explore the further reading
4. Move on to Resource 4 in this pack

CONTEXT

Enzymes are proteins which act as catalysts for reactions occurring in biological contexts. They are used throughout biology to speed up those reactions which are crucial, but which would take a long time without the aid of an enzyme.

Data Source

Lock and Key Model

One of the most commonly used models of how enzymes catalyse reactions is the lock and key model of enzyme function which is shown in the picture below. Enzymes contain a region known as the active site which is where the reaction occurs – the active site of the blue enzyme is the arrow shaped part. The active site of an enzyme is a specific shape to allow its substrate (shown here in orange) to bind and form an enzyme-substrate complex. The reaction can then take place and the resulting products will be released from the enzyme which can then bind with another substrate molecule and perform the reaction again.

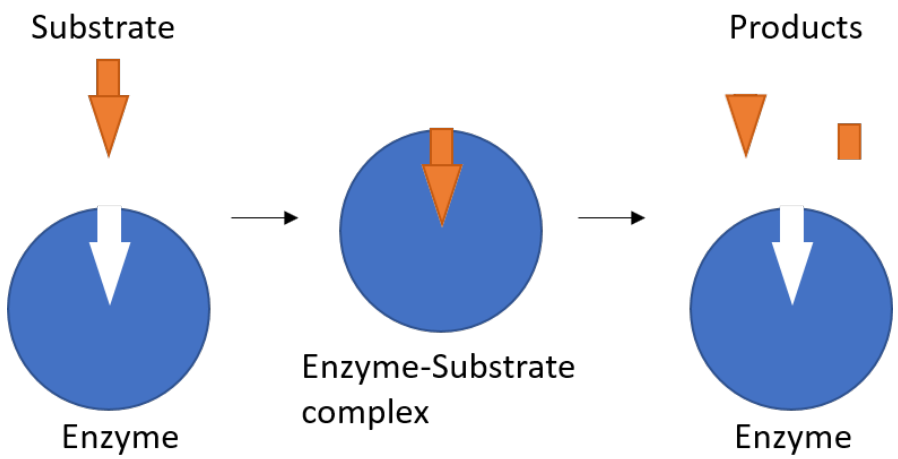


Figure 7. The Lock and Key model

The Effect of Temperature and pH

The activity of an enzyme (how well it performs) is affected by a number of different factors, including the temperature and pH of its environment. Each enzyme will have an optimum temperature and pH representing the conditions at which it works best. For example, human Flap Endonuclease 1 which works inside the nucleus of human cells has an optimum temperature of 37°C and an optimum pH of about 7. In contrast, pepsin (an enzyme present in your stomach which helps break down proteins) has the same optimum temperature of 37°C but an optimum pH of about 1.5. At temperatures and pHs away from the optimum, the activity of an enzyme will decrease. At very extreme conditions, they may also denature and lose their 3D structure so they no longer function.

Data Source (continued...)

Deep Dive

Flap Endonuclease 1 and its DNA substrate

The lock and key model is a simplification of what occurs on a real enzyme, where movement of the enzyme can help place the substrate into the active site. This is true of Flap Endonuclease 1 (FEN1), a protein which cuts DNA using water in a process called hydrolysis. The hydrolysis of two DNA nucleotides at their phosphodiester bond is a process which without help from FEN1 takes 30 million years at 25°C. With FEN1 present, this reaction can occur in less than a millisecond!

FEN1 and its preferred DNA substrate (a double flap structure) are shown in the image below. Circled in yellow is a hole found in the structure of the enzyme. At the bottom of this hole is the active site of the enzyme, and the DNA strand indicated by the black arrow has to pass through this hole in order to place the bond which is to be hydrolysed into the correct place for that reaction to take place. Without DNA present, the amino acid chain above and around this hole is flexible and less tightly folded. This makes the hole larger, allowing the DNA strand to thread through and the amino acid chain then folds more tightly around the DNA. As the image shows, the DNA substrate is bent nearly 100°. This occurs during the process of binding to FEN1 and allows the correct strand to thread into the active site and the reaction to occur at the correct place.

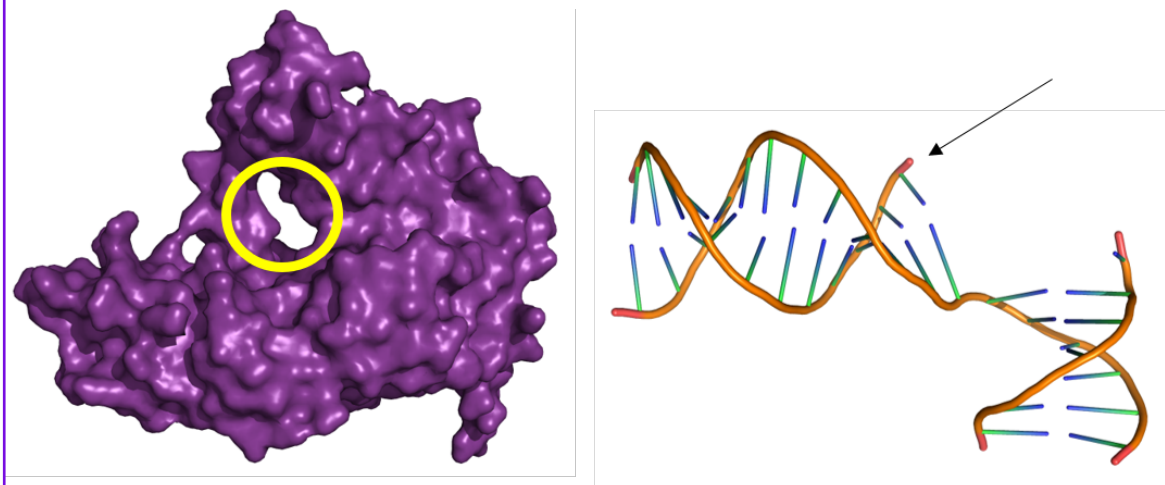


Figure 8. FEN1 and its preferred DNA substrate

Activity 1

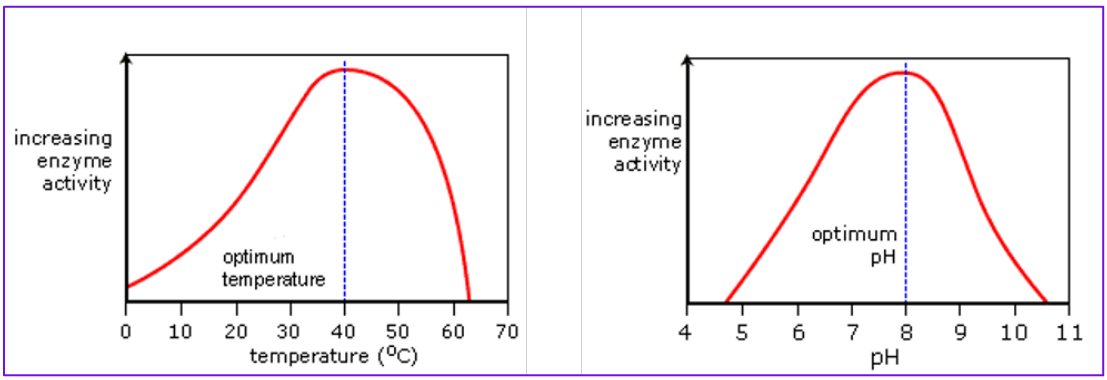
Enzymes are biological catalysts involved in many key reactions within living organisms. To understand how enzymes work it is important to know what a catalyst is.

1. Have a think about what you think a catalyst is and write down some ideas.
2. Discuss with a partner and see if you can improve your answer in any way.
3. Share with the class and come up with a final definition.
4. In at least one paragraph and using clear examples, answer the question: What is a catalyst?

RESOURCE 3

Activity 2

The graphs below show the general effect of temperature and pH on enzyme activity.



Graphs can be found at
http://www.bbc.co.uk/schools/gcsebitesize/science/add_aqa/proteins/proteinsrev3.shtml

Write at least one paragraph describing what these graphs show.

You should consider the following questions in your answer:

- What is meant by the terms optimum temperature and pH?
- What happens to the activity away from these conditions?
- What happens to an enzyme at extreme conditions?

Data Interpretation

Activity 3

Write a short paragraph (6 or 7 lines) explaining the 'lock and key model' of enzyme specificity. Look at the resource above for help and be sure to include the following words in your answer:

Enzyme
Substrate
Products
Active site
Enzyme-substrate complex

Providing evidence

Further Reading

Introduction to enzymes - http://www.worthington-biochem.com/introbiochem/Enzymes.pdf

Enzyme introduction - http://www.rsc.org/Education/Teachers/Resources/cfb/enzymes.htm

Research paper: DNA and protein requirements for substrate conformational changes necessary for human Flap Endonuclease 1 catalysed reaction - http://www.jbc.org/content/291/15/8258.full.pdf) (this paper contains some tricky science, try reading the introduction and discussion first.)

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Biochemistry Key Stage 4
www.researchbasedcurricula.com

Experimental Kinetics

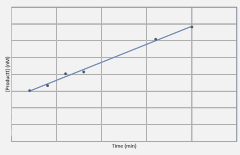
Link to curriculum
Kinetics, Rates of Reaction

TEACHER NOTE

For GCSE Additional Science students should be enabled to:

- Presenting observations and other data using appropriate methods.
- Translating data from one form to another.
- Carrying out and represent mathematical and statistical analysis.
- Interpreting observations and other data (presented in verbal, diagrammatic, graphical, symbolic or numerical form), including identifying patterns and trends, making inferences and drawing conclusions.
- Presenting reasoned explanations including relating data to hypotheses.
- Communicating the scientific rationale for investigations, methods used, findings and reasoned conclusions through paper-based and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

INSTRUCTIONS



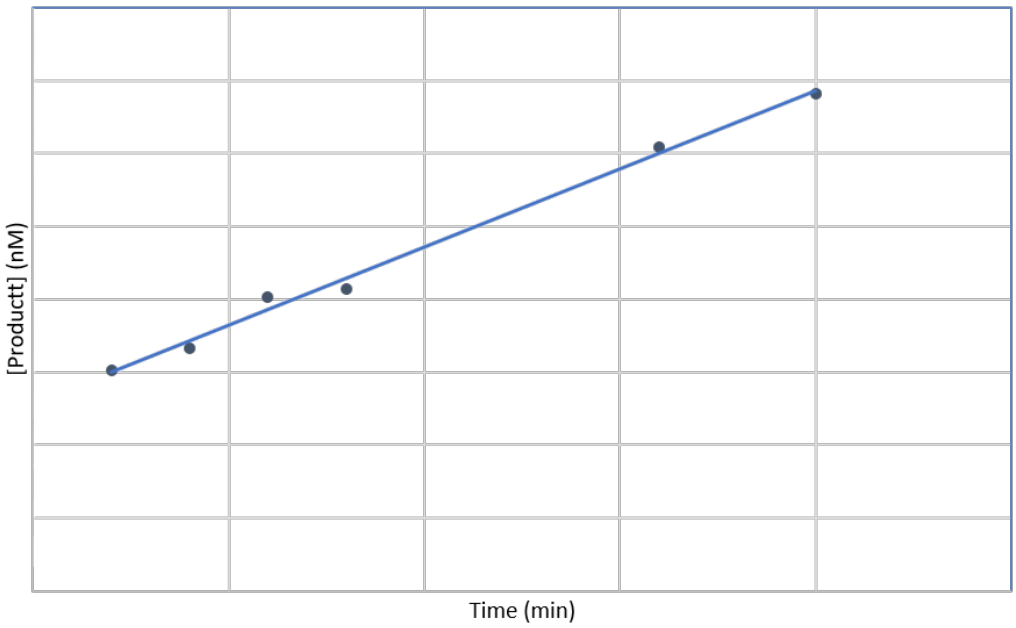
1. Read and annotate the data source
2. Complete the written activities
3. Explore the further reading
4. Move on to Resource 5 in this pack

CONTEXT

Kinetics experiments are used in biochemistry research to help researchers understand the chemical reactions that take place in living organisms. In combination with other techniques, they can help scientists understand what the best substrates for a particular enzyme are and the role of specific amino acids in the chemical reaction which is occurring.

Data Source

In my laboratory, we use kinetics to investigate the ability of an enzyme called Flap Endonuclease 1 (FEN1) to hydrolyse DNA by monitoring how much of a short DNA product is produced during a reaction. Small samples are taken from the reaction mixture after different periods of time to produce something called a reaction time-course. After analysis using a chromatography method which separates the larger, unreacted strands from the smaller ones which have been cleaved in the reaction, the data can be plotted on a graph like this one:



Concentration of short DNA products during a 20 minute reaction

Data Source (continued...)

Below is a table of data I collected to examine the effect of phosphorylation on the activity of FEN1. Phosphorylation is a process by which a phosphate group (PO_4^{2-}) is added to a protein. Phosphorylation is a change known as a Post Translational Modification (PTM). Post Translational Modifications add small molecules such as phosphate groups or larger molecules such as ubiquitin (which is a small protein) to particular amino acids of a protein. This process is often used in nature to modify the activity of an enzyme and thus can either increase or decrease the activity of that enzyme. PTMs can also be used as signals to indicate to a cell that particular proteins need to be destroyed.

The experiment carried out was designed to give information about the initial rate of reaction of FEN1 and therefore when the data is plotted on a graph it will show the maximum speed the reaction is occurring at for a particular enzyme concentration (30pM for this experiment). In order to use this information, the data must fit to a straight line when plotted on a graph rather than a curve. It has been reported by another research group that phosphorylation reduces the activity of FEN1 by 3-fold (Henneke G. et al (2003) Oncogene 22:4301-4313) and my experiment was performed to see if this was true or not. Your challenge is to work out from my data whether phosphorylation reduces the ability of FEN1 to hydrolyse DNA in my experiment.

Enzyme	Time (min)	[Product] (nM)
Phosphorylated FEN1	2	1.9
	4	3.2
	6	3.7
	8	5.1
	10	5.8
	20	9.0
FEN1	2	0.8
	4	1.7
	6	2.4
	8	3.2
	10	4.5
	12	5.5
	20	8.3

Activity 1

1. Put the information in the table onto the two graphs, one showing the reaction of FEN1 and the other the reaction of phosphorylated FEN1.
2. Draw a best-fit straight line on each of the graphs but do not allow your line to cross the y axis.

Activity 2

1. Determine the gradient of each of your best fit lines. This is the rate of reaction (**v**) for each enzyme when an enzyme concentration of 30pM is used and the units are nM/min (amount of product per minute).

Activity 3

In scientific experiments, different concentrations of enzymes can be used to speed up or slow down a reaction. It is useful for scientists to be able to compare rates of reaction for similar enzymes and substrates without worrying about the enzyme concentration used. To do this, scientists use 'normalised rates' which account for any variations in enzyme concentration.

You are now going to calculate the normalised rate for both of these enzymes.

1. Start by converting the enzyme concentration from pM to nM by dividing by 1000 (1000pM = 1nM)
2. Then use the formula below to calculate the normalised rate of reaction (units are /min).
3. When you have calculated the normalised rates, decide whether you think the rates are different enough to say that phosphorylation decreases the activity of FEN1 (use the published difference of 3-fold to help you decide).

$$\text{Normalised rate of reaction /min} = \frac{v}{[E]}$$

When the data is analysed on a computer, the normalised rate of reaction is 14.12 /min for FEN1 and 12.80 /min for phosphorylated FEN1. These values are close enough to show that in my experiments phosphorylation of the protein does not affect its activity.

Further Reading

Basics of enzyme kinetics - https://www.khanacademy.org/science/biology/energy-and-enzymes/enzyme-regulation/a/basics-of-enzyme-kinetics-graphs

Research paper: Control of structure-specific endonucleases to maintain genome stability (Dehé P-M. and Gaillard P-H. L. (2017) Nat. Rev. Mol. Cell Biol. 18:315-330).

RESOURCE 5

Speeding Up or Slowing Down

Link to curriculum
Kinetics, Rates of Reaction

TEACHER NOTE

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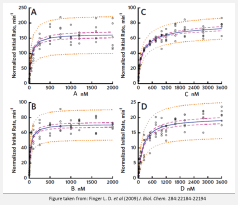
- Presenting reasoned explanations including relating data to hypotheses.
- Communicating the scientific rationale for investigations, methods used, findings and reasoned conclusions through paper-based and electronic reports and presentations using verbal, diagrammatic, graphical, numerical and symbolic forms.

INSTRUCTIONS



1. Read and annotate the data source
2. Complete the written activities
3. Explore the further reading
4. Move on to Resource 6 in this pack

INSTRUCTIONS

The data opposite was published as part of a scientific paper in the Journal of Biological Chemistry in 2009 and examines the rate of reaction of Flap Endonuclease 1 (FEN1) with four different DNA substrates (A, B, C and D). The y-axis on each graph shows the amount of product produced per minute and the x-axis the concentration of DNA substrate.

Data Source

These graphs collect together the initial reaction rates for a range of substrate concentrations for each different substrate with at least 6 repeats for each concentration. The value of the reaction rate at the point when the graphs flatten off is called the maximum velocity, V_{max} and the substrate concentration which gives half this rate is known as K_M and gives scientists an idea of how well the substrate binds to the enzyme.

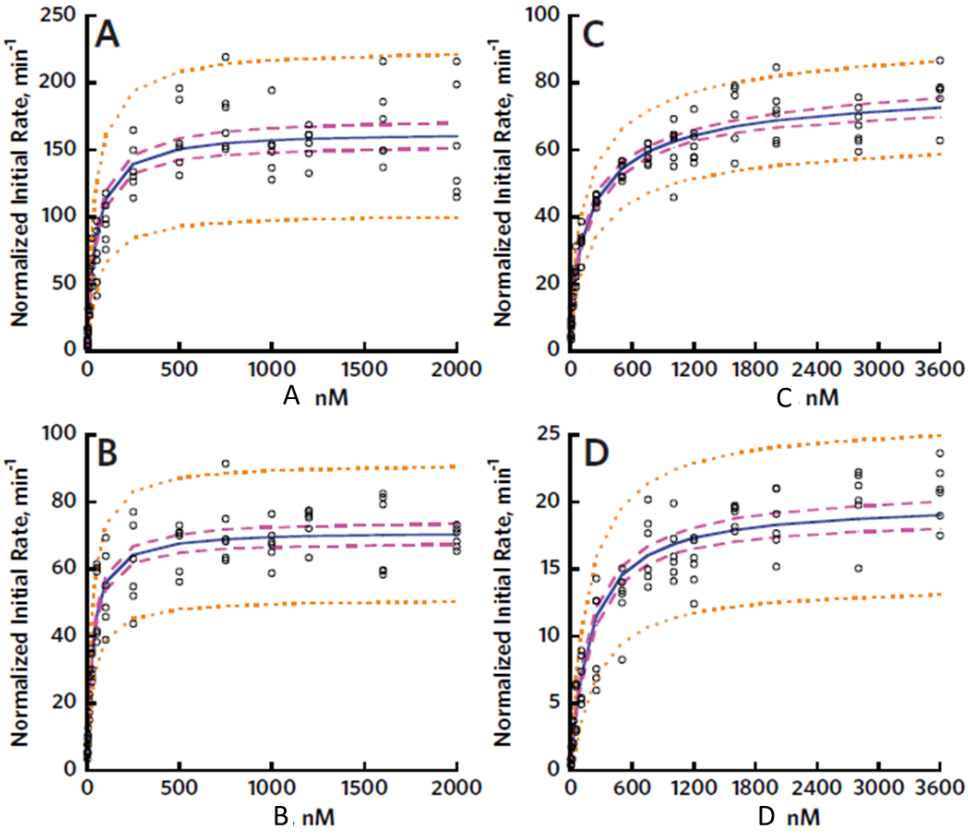


Figure taken from: Finger L. D. *et al* (2009) *J. Biol. Chem.* 284:22184-22194

Figure 8

Data Source (continued...)

The structure of the substrates used in the experiments are shown below. They represent different biologically relevant DNA structures which are found in cells and which have the potential to be cleaved by FEN1. The structures are named based on their features:

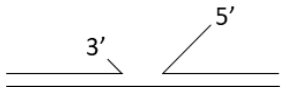
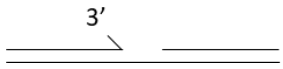
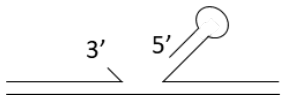
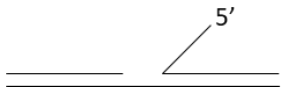
A	*Double Flap substrate*	*Has both a 1 nucleotide long 3' flap and a longer 5' flap*	
B	*Exo substrate*	*Has a single nucleotide 3' flap only*	
C	*Gen substrate*	*Has a single nucleotide 3' flap and a double stranded 5' helix with a hairpin at the end*	
D	*Single Flap substrate*	*Has a long 5' flap only*	

Figure 8.

Activity 1

The graphs in Figure 8. all show that increasing the substrate concentration increases the rate of reaction. What is happening in the reaction mixture to explain this?

Activity 2

Bearing in mind you answer to activity 1, what do you think is happening at the point when the graphs level out ?

Activity 3

The lock and key mechanism says that an enzyme will bind to a specific substrate allowing it to react to produce specific products (like using a key to unlock a door). The wrong substrate will not fit the enzyme properly and no reaction will be catalysed (like trying to use the wrong key to unlock a door). The same is true for chemical catalysts which will speed up the reaction of specific substrates to produce specific products. The graphs shown in the image show that different substrates (A-D) react at different rates when their enzyme catalyst (FEN1) is present.

1. Using the information and the substrate diagrams above why do these different substrates react at different rates? (Note: one of the substrates shown is the correct substrate for FEN1, the others have some aspects of their shape which are similar to the correct substrate, but they are not the same.)

2. Looking at the graphs, write down the four substrates in order from the best substrate (which reacts with the fastest rate) to the worst substrate (with the slowest rate). (Hint: look at the axes of the graphs)

Activity 4

Write a list of as many things as you can think of that can change (increase or decrease) the rate of a chemical reaction.

Further Reading

Basics of enzyme kinetics - https://www.khanacademy.org/science/biology/energy-and-enzymes/enzyme-regulation/a/basics-of-enzyme-kinetics-graphs

BBC Bitesize background information about the rates of chemical reactions - http://www.bbc.co.uk/schools/gcsebitesize/science/add_edexcel/chemical_reactions/ratesrev1.shtml

Rates of reaction experiment - https://www.youtube.com/watch?v=Gl6LVl7oAlU

GCSE Biology Revision – DNA

What is DNA?

DNA — The molecule which contains genes. It's shaped like a double helix (a spiral)

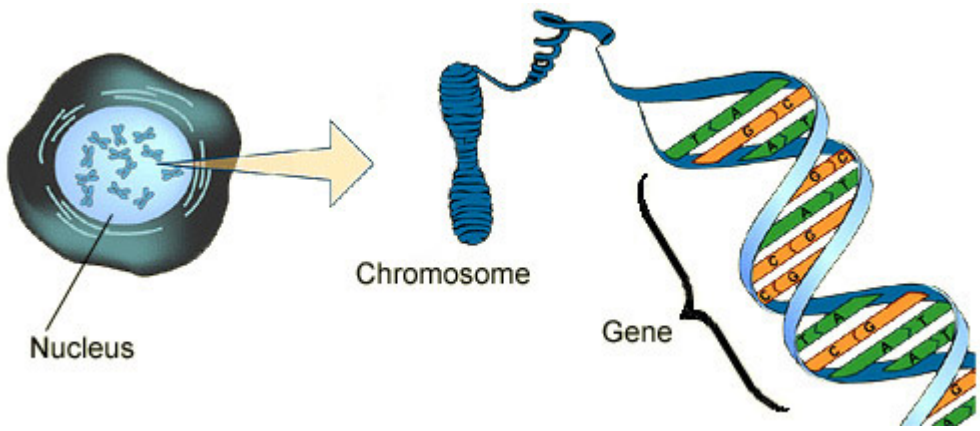
DNA is the complex chemical that carries genetic information. DNA is contained in chromosomes, which are found in the nucleus of most cells. The gene is the unit of inheritance and different forms of the same gene are called alleles.

Chromosomes

Chromosomes are X-shaped objects found in the nucleus of most cells. They consist of long strands of a substance called deoxyribonucleic acid, or DNA for short. A section of DNA that has the genetic code for making a particular protein is called a gene.

The gene is the unit of inheritance, and each chromosome may have several thousand genes. We inherit particular chromosomes through the egg of our mother and sperm of our father. The genes on those chromosomes carry the code that determines our physical characteristics, which are a combination of those of our two parents.

The bases in the DNA molecule carry the different codes needed for different amino acids. The code for a particular amino acid is made from three bases in a particular order.



Alleles

Different forms of the same gene are called alleles - pronounced 'al-eels'. You inherit one allele for each gene from your father and one allele for each gene from your mother. For example, the gene for eye colour has an alleles for blue eye colour and an alleles for brown eye colour. Your eye colour will depend on the combination of alleles you have inherited from your parents.

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Electrophoresis in the Lab

Link to curriculum
Electrophoresis

TEACHER NOTE

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- Translating data from one form to another.
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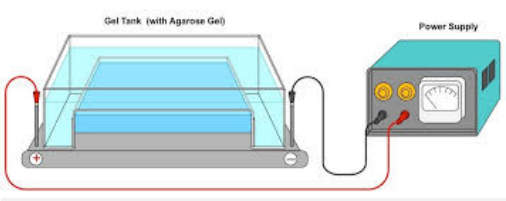
INSTRUCTIONS



1. Read and annotate the data source
2. Complete the written activities
3. Explore the further reading
4. You can share any work you produce with the researcher who created this pack by sending it to assignments@access-ed.ngo
5. Find out more about studying Physics at university

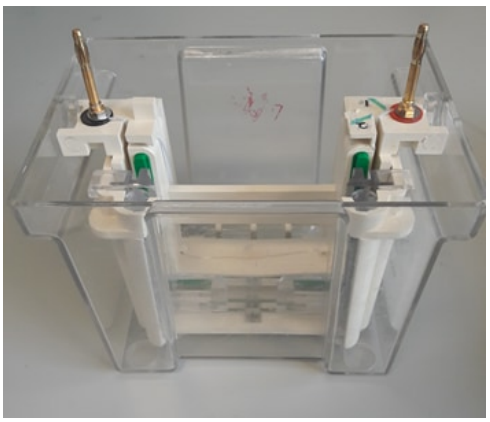
CONTEXT

Electrophoresis is an application of electrolysis regularly used in research to separate molecules on a gel. These gels can give vital information about whether a reaction or procedure has worked and can also be used to purify molecules of different sizes.

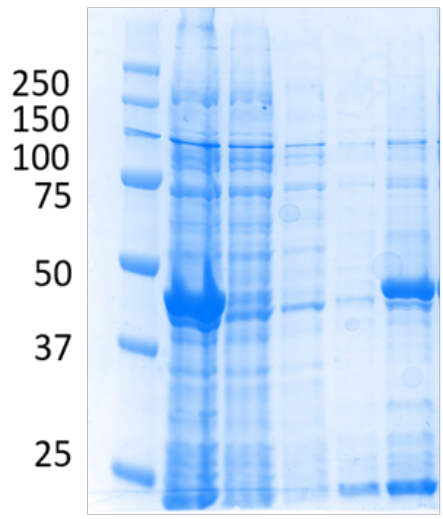
Data Source

SDS PAGE Gels

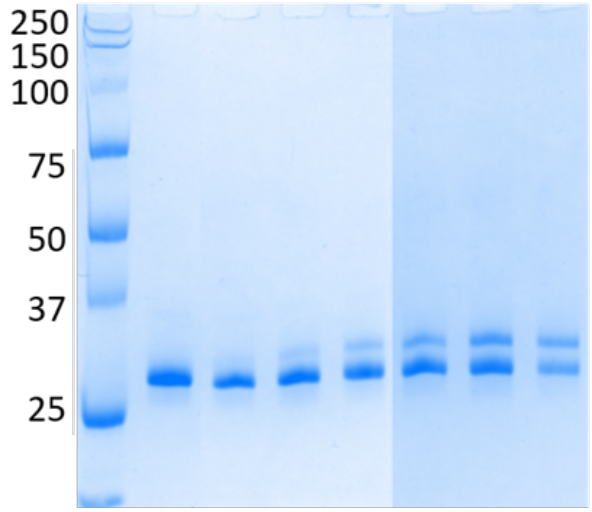
SDS PAGE (Sodium Dodecyl Sulphate PolyAcrylamide Gel Electophoresis) gels can be used to separate protein molecules in a reaction mixture. The gels are made from a polymer called polyacrylamide and are run vertically in a tank like this one, meaning gels are run from top to bottom.



Proteins are prepared by coating them in a negatively charged molecule called Sodium Dodecyl Sulphate (SDS) which means that when a current is applied to the gel the proteins will move towards the positively charge electrode at the bottom of the tank. A dye can then be used to stain the protein to allow them to be seen – on the gels below, a blue stain called Coomassie Blue has been used.



SDS PAGE gel 1

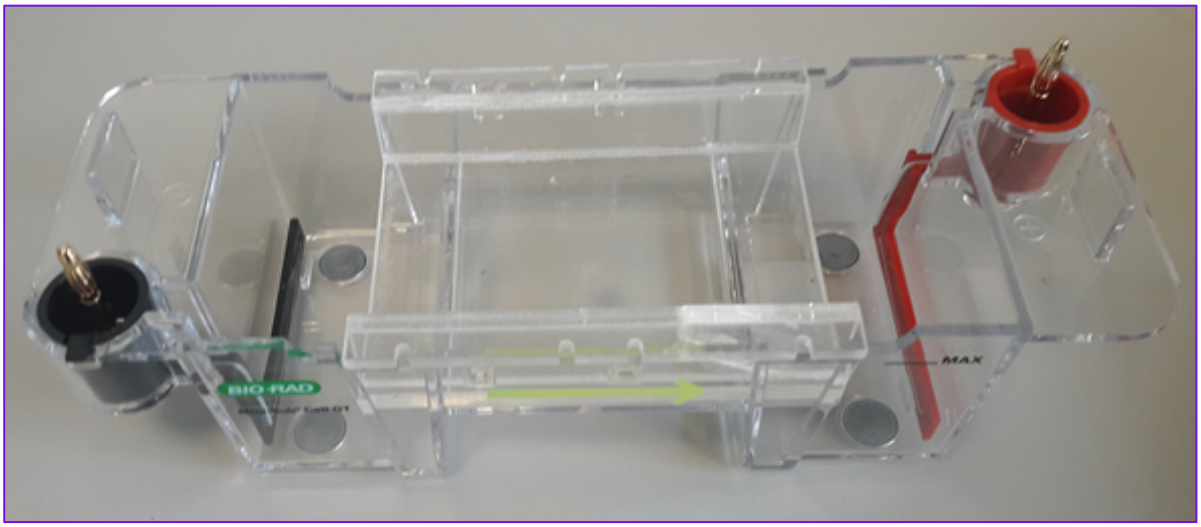


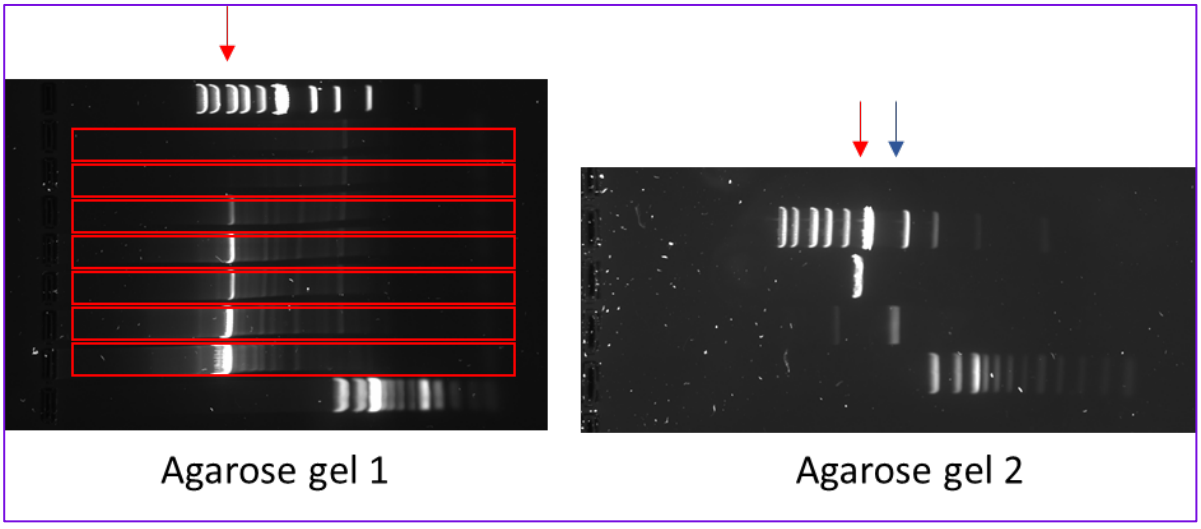
SDS PAGE gel 2

Data Source (continued...)

Agarose Gels

Agarose gels can be used to separate DNA and are made from poly-agarose. The double-helical structure of DNA means that the outside of the helix is negatively charged (due to the phosphate backbone) and therefore DNA will move towards the positively charged red electrode. Agarose gels are run in a horizontal tank as shown below and a coloured dye is added to the samples before running and another is added to the gel before it is made which allows the DNA to be imaged using UV light.





Agarose gel 1

Agarose gel 2

Activity 1

What is electrolysis ?

Activity 2

The gels used for gel electrophoresis are made up of a network of irregular pores created by polymer molecules. This means that proteins or DNA moving through the gels are separated by means of their size with smaller fragments/molecules moving further down the gel and larger ones remaining near the top.

Write at least 2 sentences to explain why this is.

Activity 3

Gel electrophoresis is used as a diagnostic tool to help researchers work out whether their reactions or processes have worked or not. To give you an idea of the kind of questions which can be answered using gels, you are going to analyse the four gels shown above which all provide different information to a researcher.

SDS PAGE gel 1: This follows four steps in the purification of FEN1. The desired outcome is to go from the initial sample containing lots of protein (in the second lane from the left) to one band in the far right lane which will be between the 37 and 50 marks in the protein ladder (the protein ladder is in the far left lane). Looking at the gel, has the protein purification worked? What do you think might be the problem with the final sample shown on this gel?

SDS PAGE gel 2: A special reagent has been added to this gel to allow us to see if FEN1 has had a phosphate group added during a reaction. Normal FEN1 can be seen in the bottom band (just above the 25 band in the protein ladder) with phosphorylated FEN1 appearing just above it. Each lane shows a different time point during the reaction, taken (from left to right) after 0, 5, 10, 20, 30, 45 and 60 minutes. From the gel, how long do you think it takes before FEN1 starts to be phosphorylated? After 60 minutes is all of the FEN1 phosphorylated?

Activity 3 (continued...)

Agarose gel 1: This gel was used to analyse whether a reaction called a PCR (Polymerase Chain Reaction) has worked or not. There are 7 different reactions shown on this gel and if they have worked there should be a band where the red arrow is indicating. The brightness of the band seen depends on how much DNA is present, the more DNA, the brighter the band. From this gel, how many of the PCR reactions analysed have worked?

Agarose gel 2: This gel is used to determine whether a reaction to open a circular DNA plasmid to form an open strand of linear DNA has worked. The band of DNA indicated by the blue arrow shows the circular plasmid in its original state and the band indicated by the red arrow shows that the reaction has worked and the DNA is now linear. Above, I told you that smaller molecules move further down the gel through the pores of the gel. Both the circular and linear DNA in this case is the same size but the circular DNA moves further down the gel. Why do you think this is ?

Further Reading

Introduction to electrolysis - https://www.youtube.com/watch?v=7ullq_Ofzgw&t=2s

Gel electrophoresis - https://en.wikipedia.org/wiki/Gel_electrophoresis (remember that Wikipedia is a great resource for background information but you should always check that what you are reading has references for the information – these can be found at the bottom of the page)

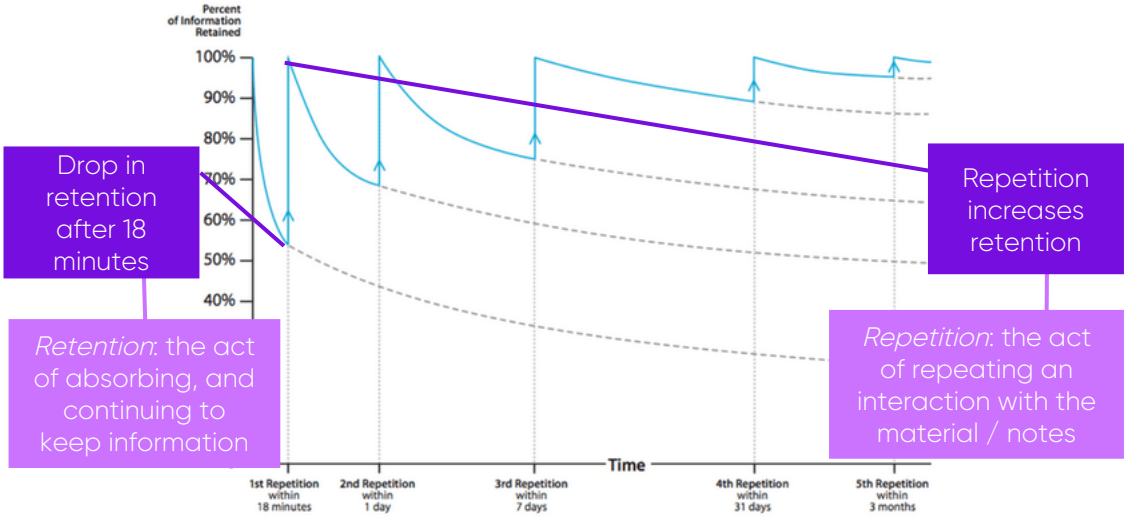
PART 3: ADVICE AND GUIDANCE

University Study Skills: Cornell Notes

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.

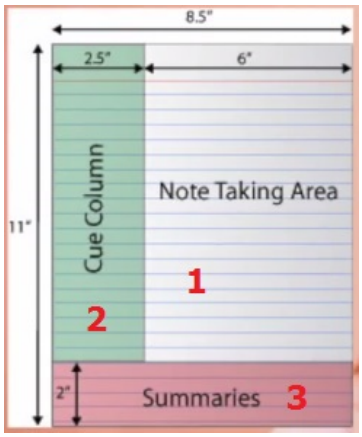
If we take notes effectively, however, we can retain and retrieve almost 100% of the information we receive. Consider this graph on the rate of forgetting with study/repetition:



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. <u>Create Format</u>: 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. <u>Write and Organise</u>: You then take your notes in area on the right 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.

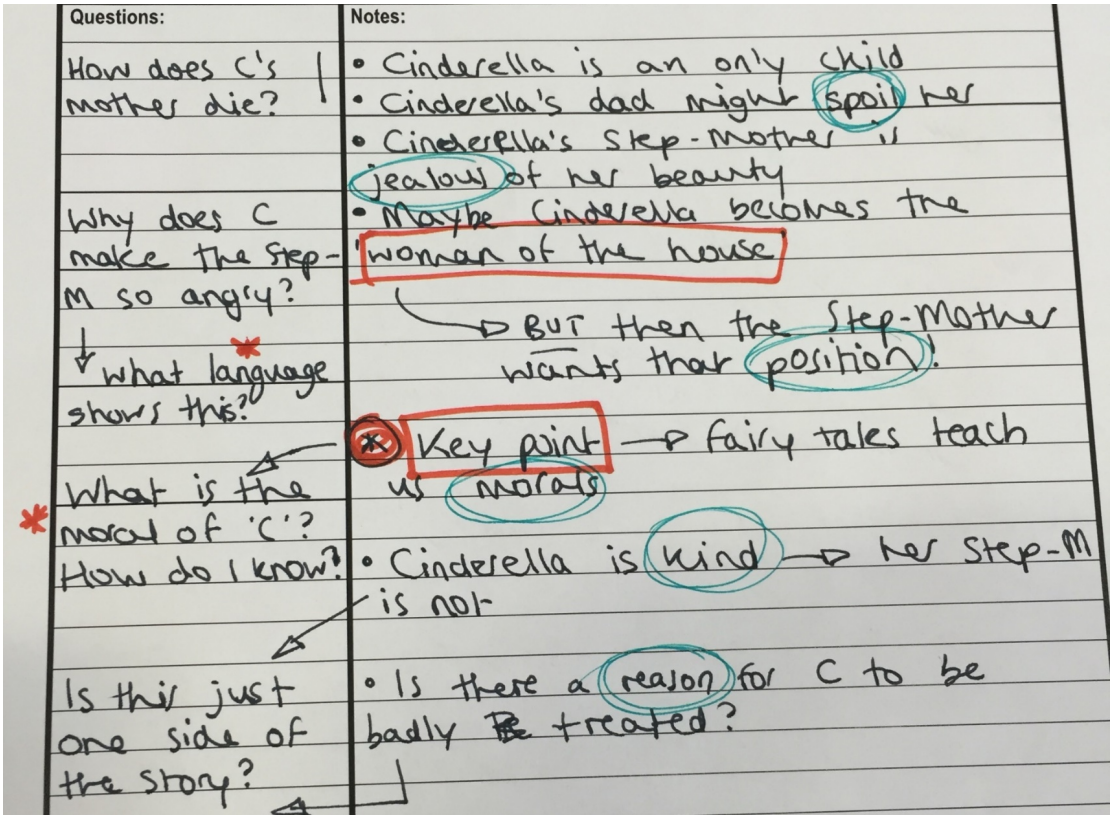
Step 2 Note-Making

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:

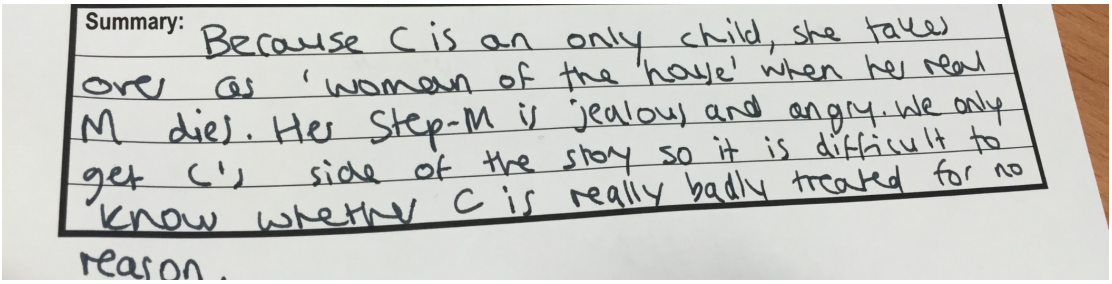
- Which is most important / significant reason for…
- To what extent…
- How does the (data / text / ideas) support the viewpoint?
- How do we know that…

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



Step 3 Note-Interacting

1. 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 youu 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 on – 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 of 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.

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. Basically, 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.

Exploring Careers and Study 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 what 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

- ✓ https://www.whatuni.com/
- ✓ http://unistats.direct.gov.uk/
- ✓ https://www.thecompleteuniversityguide.co.uk/
- ✓ Which? Explorer tool – find out your degree options based on your A level and BTEC subjects: https://university.which.co.uk/

UCAS

- ✓ Key dates and deadlines: https://university.which.co.uk/advice/ucas-application/ucas-deadlines-key-application-dates
- ✓ Untangle UCAS terminology at https://www.ucas.com/corporate/about-us/who-we-are/ucas-terms-explained
- ✓ Get advice on writing a UCAS personal statement at https://www.ucas.com/ucas/undergraduate/getting-started/when-apply/how-write-ucas-undergraduate-personal-statement
- ✓ You can also find a template to help you structure a UCAS statement, at https://www.ucas.com/sites/default/files/ucas-personal-statement-worksheet.pdf
- ✓ How to survive Clearing: https://university.which.co.uk/advice/clearing-results-day/the-survivors-guide-to-clearing

Biochemistry at University

- ✓ Biochemists investigate the chemical processes that take place inside all living things.
- ✓ Biochemists will need a high level of skill and ability in science and be good at solving problems. Working accurately and having an eye for detail will help you when examining samples under a microscope.
- ✓ You can find out more about different courses and entry requirements by exploring the UCAS Biology Guide online: https://www.ucas.com/ucas/subject-guide-list/biological-sciences
- ✓ You can find out more about the different careers by exploring the UCAS Biochemists Careers online; https://www.ucas.com/ucas/after-gcses/find-career-ideas/explore-jobs/job-profile/biochemist

A Deeper Look Into Biochemistry

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- ✓ **Read:** New Scientist Magazine https://www.newscientist.com
- ✓ **Read:** Nick Lane (2010) Life Ascending: The Ten Great Inventions of Evolution
- ✓ **Browse:** Natural History Museum http://www.nhm.ac.uk
- ✓ **Browse:** Science Museum https://www.msimanchester.org.uk; https://www.visitmagna.co.uk/education

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