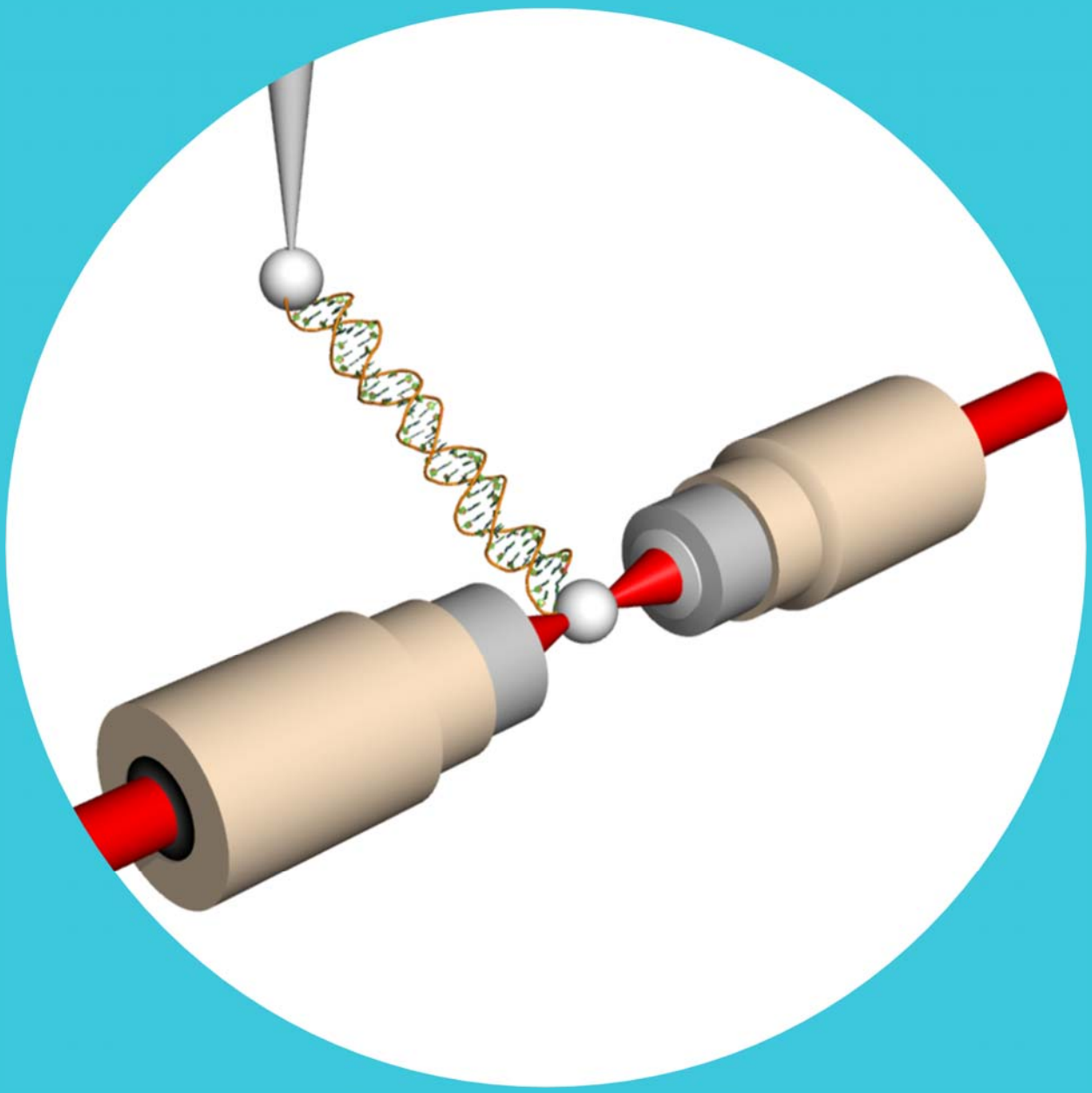

Stretching DNA with tweezers made of light

Key Stage 4 Programme

Pupil Name	
Handbook Designed by	Dr Murugesapillai

Timetable and Assignment Submission

Timetable – Tutorials

Tutorial	Date	Time	Location
1			
2			
3			
4			
5			
6 (Feedback)			
7 (Feedback)			

Timetable – Homework Assignments

Homework Assignment	Description	Due Date
Tutorial 1		
Tutorial 2		
Tutorial 3		
Tutorial 4		
Tutorial 5		

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on 9th August	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Uni Pathways – Pupil Feedback Report

Grade	Marks	Guidance
1st	70+	
2:1	60-69	
2:2	50-59	
3rd	40-49	
Working towards a pass	0-39	
Did not submit	DNS	No assignment received by The Brilliant Club

Lateness	
Any lateness	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Name of PhD Tutor			
Title of Assignment			
Name of Pupil			
Name of School			
ORIGINAL MARK / 100		FINAL MARK / 100	
DEDUCTED MARKS		FINAL GRADE	
If marks have been deducted (e.g. late submission, plagiarism) the PhD tutor should give an explanation in this section:			
Learning Feedback Comment 1 - ***Enter Key Learning Priority Here***			
What you did in relation to this Key Learning Priority *Enter feedback here*		How you could improve in the future *Enter feedback here*	
Learning Feedback Comment 2 – ***Enter Key Learning Priority Here***			
What you did in relation to this Key Learning Priority *Enter feedback here*		How you could improve in the future *Enter feedback here*	
Learning Feedback Comment 3 – ***Enter Key Learning Priority Here***			
What you did in relation to this Key Learning Priority *Enter feedback here*		How you could improve in the future *Enter feedback here*	
Resilience Comment			
How you showed learning resilience during the course *Enter feedback here*		How you could build learning resilience in the future *Enter feedback here*	

Contents

Course Rationale	**PX**
Mark Scheme	**PX**
Glossary of Keywords	**PX**
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Tutorial 2	**PX**
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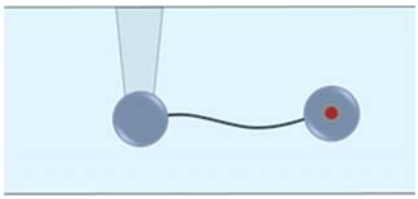
Course Rationale

This course is designed for pupils to learn about the interactions between DNA molecules and proteins. When we understand the interactions between these molecules, we can learn about how they function. These molecules can be proteins or small molecules such as drugs. They are either DNA binding proteins or DNA binding drugs. Understanding how these molecules work will help us to rationally design drugs. For example, the interactions between a DNA molecule and proteins (or drugs) will tell us about the affinity of the protein (or drug) to DNA, thus we can obtain an accurate measure of the quantity to prescribe to patients. Not knowing the right quantity to administrate to patients may lead to an overdose or in the case of small dose to the inefficacy of the proteins (or drugs) to combat illness. These molecules are very small. To understand what is happening in this small world we need use highly sophisticated physical instruments. One such instrument is the optical tweezers. To further understand these interactions, we will also use atomic force microscopy to visualise DNA-protein interactions.



In 2018 Arthur Ashkin had been awarded the Nobel prize for the invention of optical tweezers which enable scientists to grab atoms, viruses, and living cells as well as other small particles. In these tutorials we'll learn how to use highly focused laser beams to trap and manipulate small objects as with tweezers. Using optical tweezers, we can probe single molecules with nanometer precision and piconewton accuracy. We can measure these tiny forces exerted by biomolecules such as proteins on DNA. In these tutorials we'll also learn about the properties of the DNA molecules. For example, how does a 2 meters long DNA molecule reside in a small nucleus? What role do the proteins in the nucleus play in order to compact DNA?

The overall aims of the course are:

- To understand that light can be used to manipulate small molecules such as DNA and learn about the properties of DNA.
- To learn how to carry out analysis of experimental data
- To learn how to write a scientific report by completing the assignments given in the tutorials
- To be exposed to university style tutorials and cutting-edge research carried out in university labs

Mark Scheme

STEM Mark Scheme

Skills	1st (70-100)	2:1 (60-69)	2:2 (50-59)
Knowledge and Understanding	• All content included is relevant to the general topic and to the specific question/title • Good understanding of all the relevant topics. • Scientific terms are defined and used accurately throughout • Clear justification on how the content included is related to the specific issues that are the focus of the assignment	• Most of the content included is relevant to the general topic and to the specific question/title • Good understanding of most the relevant topics • Scientific terms are used accurately but not always clearly defined. • Adequate justification on how the content included is related to the specific issues that are the focus of the assignment	• Some of the content included is relevant to the general topic and to the specific question/title • Good understanding on some of the relevant topics but occasional confusion on others. • Scientific terms are used mostly accurately with occasional confusion and often not defined. • Some justification on how the content included is related to the specific issues that are the focus of the assignment
Critical Evaluation/ Problem solving	• Moved beyond description to an assessment of the value or significance of what is described • Evaluative points are consistently explicit/systematic/reasoned/justified • Effective critiques on the reliability of sources provided • Consistently demonstrate clear, analytical and logical steps to solving problems	• Mostly description but some assessment of the value or significance of what is described • Evaluative points are mostly explicit/systematic/reasoned/justified • Some evidence of critiques on the reliability of sources provided • Some examples of solving problems but not consistently clear, analytical and logical	• Only description with minimal assessment of the value or significance of what is described • Evaluative points are at times explicit/systematic/reasoned/justified • Limited evidence of critiques on the reliability of sources provided • Demonstrate clear steps to solving problems but not consistently analytical or logical

Structure and Presentation	• Ideas are presented in paragraphs and arranged in a logical structure that is appropriate for the assignment • The introduction clearly outlines how the essay/report will deal with the issues • The conclusion summarises all the main points clearly and concisely • All calculations, formulas and methods are clearly structured, clear to follow and correct • Tables and graphs are effectively constructed including appropriate headings, units and scales. • All sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure that is mostly appropriate for the assignment • The introduction adequately describes how the essay/report will deal with the issues • The conclusion summarises most of the main points clearly • Calculations, formulas and methods are mostly structured, clear to follow and correct • Most tables and graphs are well constructed • Most sources are referenced correctly in an agreed format	• Ideas are presented in paragraphs and arranged in a structure • The introduction mentions how the essay/report will deal with the issues • The conclusion summarises some of the main points clearly • Calculations, formulas and methods are not always structured, clear to follow and correct. • Some tables and graphs are well constructed but contains some errors • Some sources are referenced correctly in the agreed format with occasional errors

Subject Vocabulary

Word	Definition	In a sentence
DNA		
Protein		
Molecule		
Base pair		
Polymer		
Monochromatic		
Polychromatic		
charges		
LASER		
Biomolecule		
Gaussian beam		

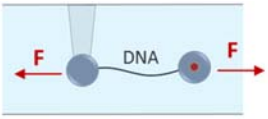
Knowledge Organiser

Key ideas

DNA is a negatively charged molecule.

A protein is a positively charged molecule.

DNA and proteins may interact or bind electrostatically.

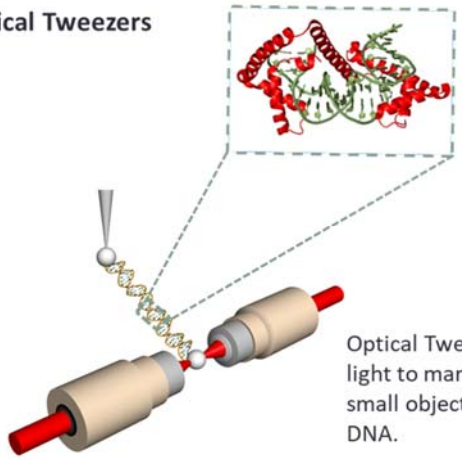


Very small forces can be applied to a single molecule of DNA

All the experiments are carried out in a fluidic cell.

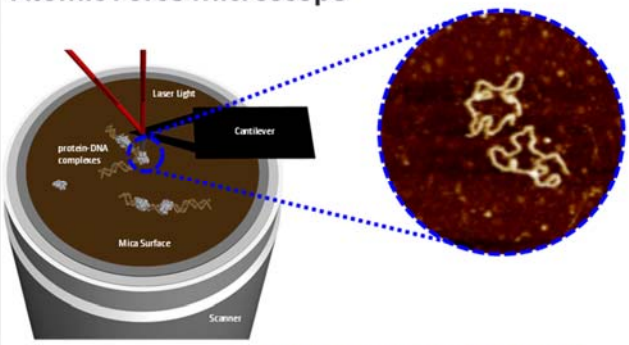
A high power laser light is used to trap biomolecules

Optical Tweezers



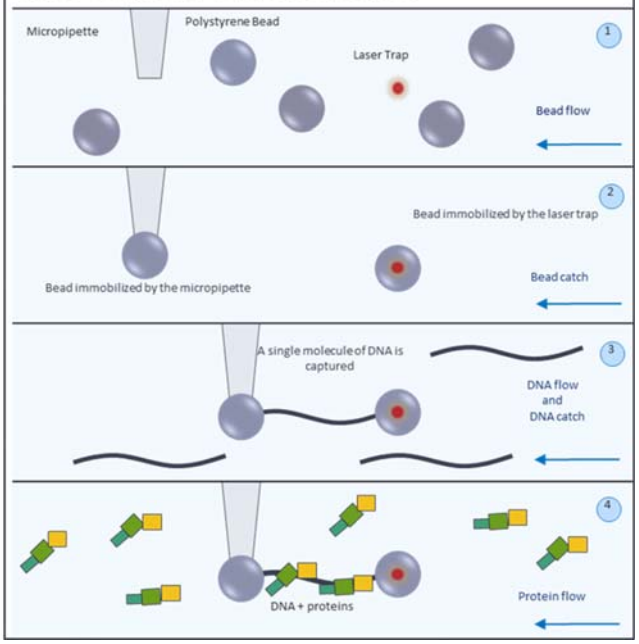
Optical Tweezers use light to manipulate small objects such as DNA.

Atomic Force Microscope

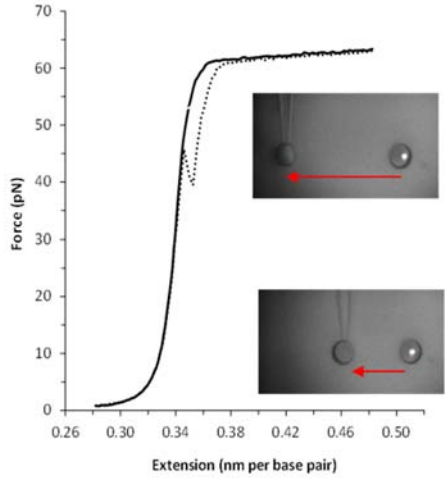


AFM can resolve protein-bound locations from DNA only

How to trap a DNA molecule?



Force-Extension curve of a DNA molecule

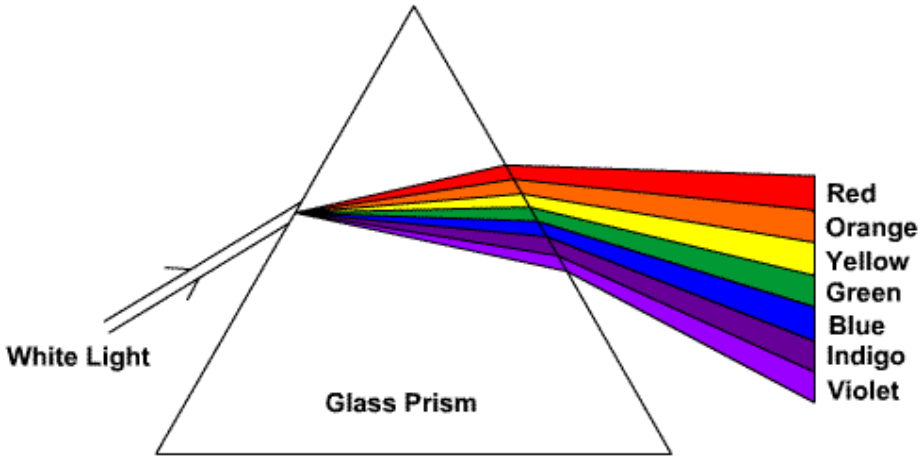


Tutorial 1 – How to use light to build an optical trap?

What is the Purpose of Tutorial 1?

- Previous knowledge about light
- Understanding the laser light and gaussian beam
- Manipulating light to capture objects

Activity 1: Polychromatic light and monochromatic light



What is a polychromatic light? What is a monochromatic light? Can you give an example for each case?

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Why is the white light bent after entering the prism? Why are there many colours? Why are the colours distributed in an ordered fashion? Do light travel at the same speed in air and in the prism?

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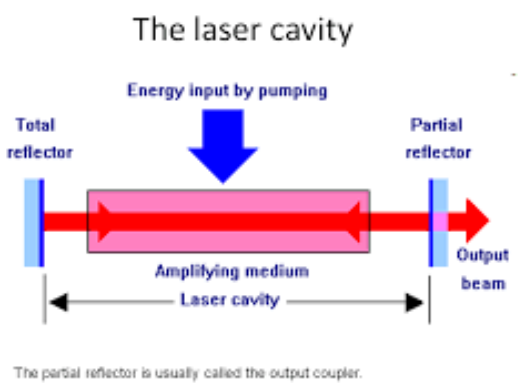
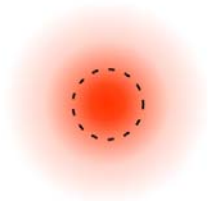
Activity 2: Laser light and gaussian beam



Gaussian beam



Can you describe in your own words how a laser work? Can you describe the distribution of the intensity of the gaussian beam?

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Can you state any other examples where a laser is used?

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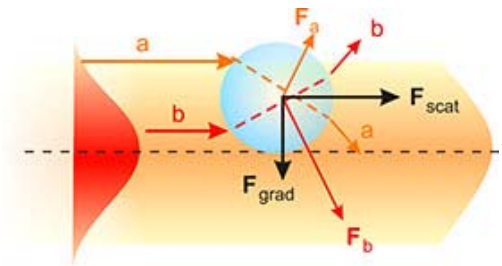
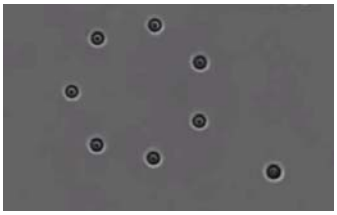
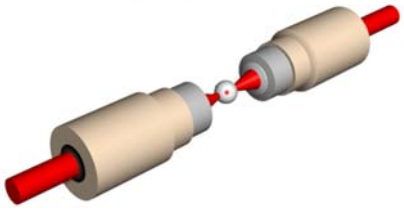
Activity 3: Trapping small objects with light (Biophysical technique)







How many forces can you see? Can you describe the meaning of each force? What will happen if the bead is placed in the middle or at the bottom of the laser beam?

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What the bead should be made of for light to go through?

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Vocabulary

Word	Definition	In a sentence

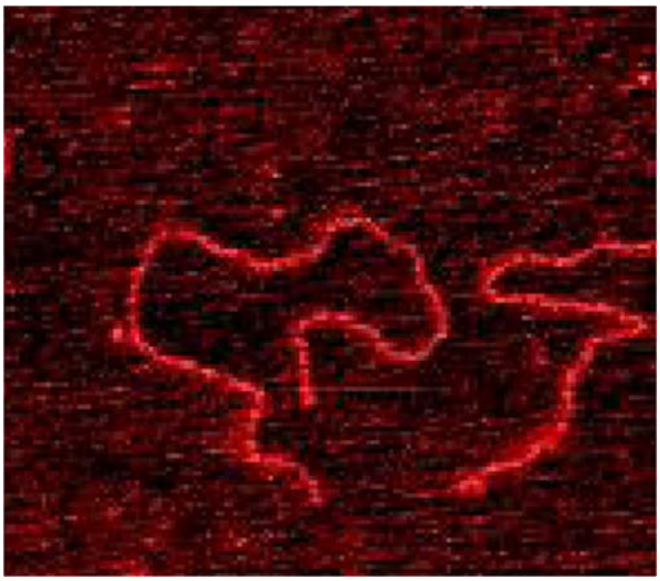
Homework 1

Write a short scientific report (2 pages- 500 words)

1. Chose a protein which interacts with DNA
   To do this, you need to do some research about proteins which interact with DNA. Choose one protein in the HMGB family of proteins. The protein of your choice can either interact with nuclear DNA or the DNA you find in mitochondria. Remember to include to source of your finding.

2. Write the report
   a) About the protein (Include research finding from a wide range of sources)
   b) Methods (Biophysical technique used- use images to describe)
   c) Results (Two new facts discovered about the protein, use data)
   d) Discussion (What do we learn new about the protein and connect the finding with existing literatures)
   e) References (You need to write the source of your finding. This can be written at the end of the report. Make sure you have reference everything correctly. Select relevant research evidence to back up your thinking)
   f) Make sure that your spelling, grammar and punctuation are accurate.

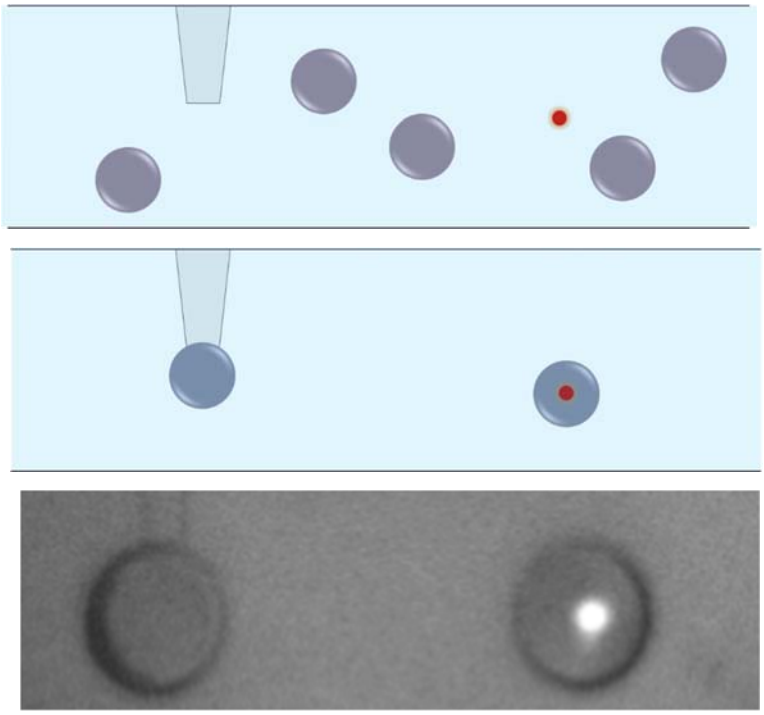
Tutorial 2 – How to trap DNA?



What is the Purpose of Tutorial 2?

- Understanding DNA trapping
- Understanding biotin-streptavidin chemical bond
- Understanding how to tether DNA
-

Activity 1: Trapping beads



Describe how the beads are trapped.

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Activity 2: Chemical bonding

What type of bonds are involved in attaching the DNA molecule to the bead?

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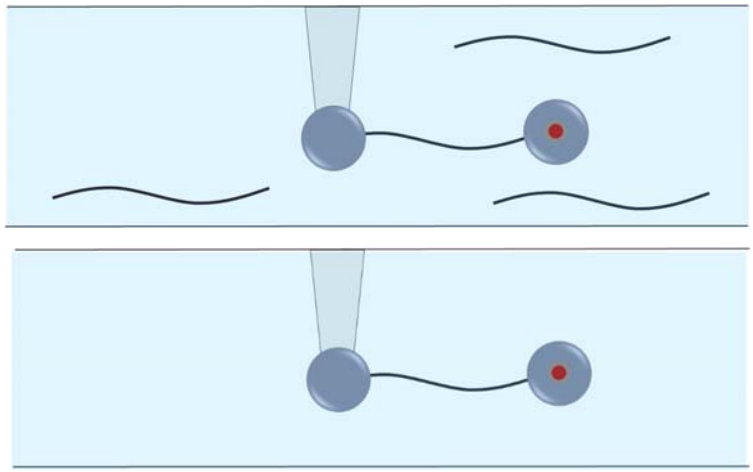
Activity 3: DNA 'fishing'



Describe the steps involved in catching a single molecule of DNA.

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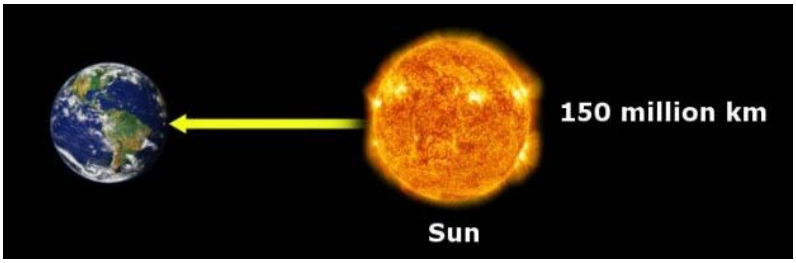
Vocabulary

Word	Definition	In a sentence

Homework 2

1) The length of a DNA in a single cell is 2 meters.
A human being has approximately 10^{14} cells.
What is the total length of the human DNA (in Km)?

2) The distance from Earth to Sun is 1.5×10^{8} Km.
What ratio does the DNA length to Earth-Sun distance represent?



Tutorial 3 – How to manipulate DNA?

What is the Purpose of Tutorial 3?

- Understanding that DNA is a rigid polymer
- Understanding the forces require to stretch a DNA molecule
- Understanding the stretching curve of a DNA molecule

Activity 1: Single stranded DNA versus double stranded DNA

Compare single stranded DNA molecule and double stranded DNA molecule, which molecule has the greatest persistence length?

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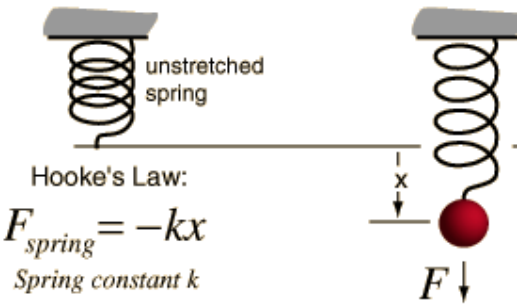
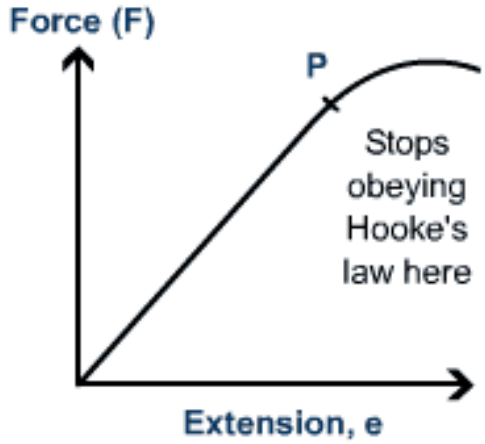
Activity 2: Force versus extension curve





Describe how to obtain a force extension curve.

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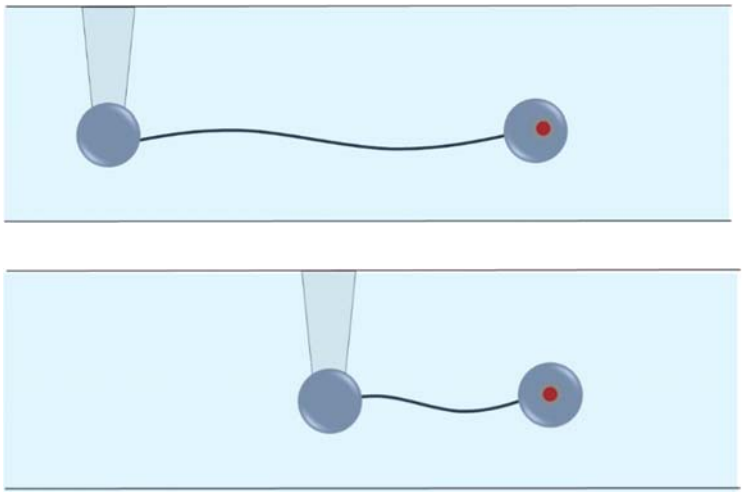
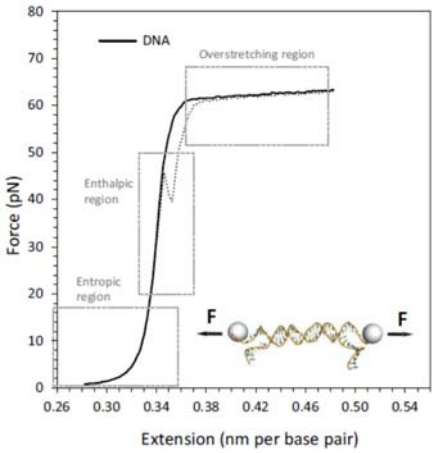
Activity 3: Stretching a single molecule of DNA





How is the change in extension recorded?

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Homework 3

1) Could you describe the DNA force-extension curve? Compare it with Hook's force-extension curve.

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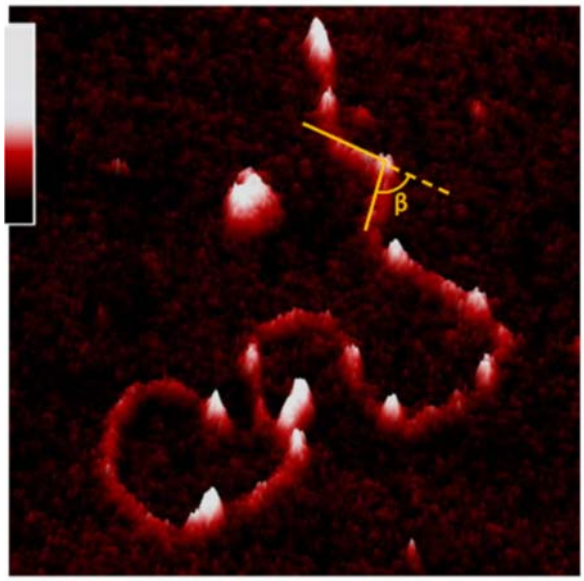
Vocabulary

Word	Definition	In a sentence

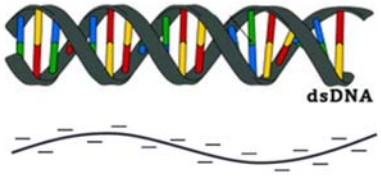
Tutorial 4 – How to characterise the interaction between DNA and protein



What is the Purpose of Tutorial 4?

- Understanding electrostatic binding of DNA with proteins
- Understanding DNA looping
- Understanding how to analyse force-extension curve

Activity 1: Charged biomolecules



What are the charges of the biomolecules?

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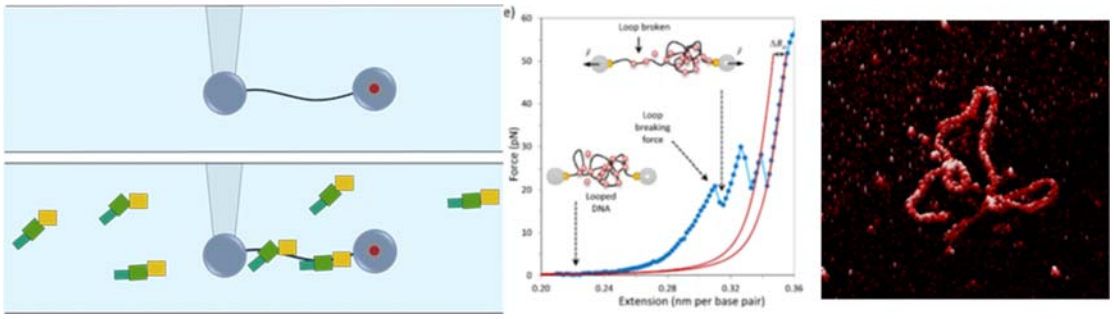
Activity 2: DNA-protein interactions



How do the proteins interact with DNA? What do the jumps represent?

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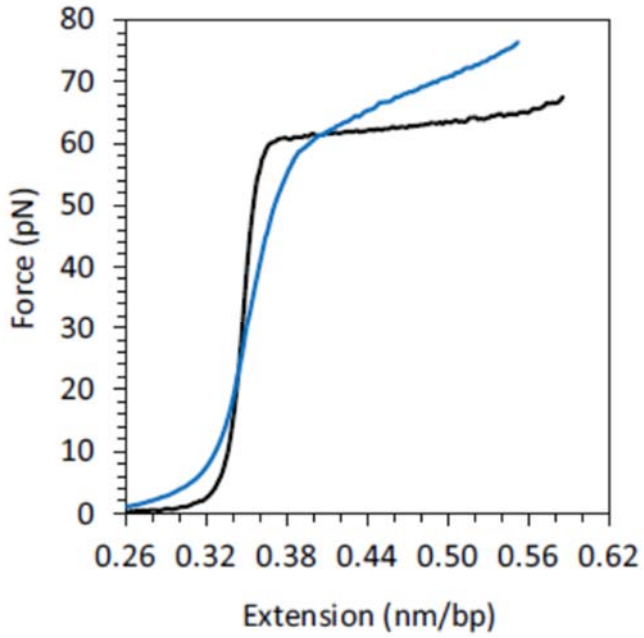
Activity 3: Analysing force-extension curve



Calculate the change in contour length at 30pN. What does the change mean? What is the change in extension at 63 pN?

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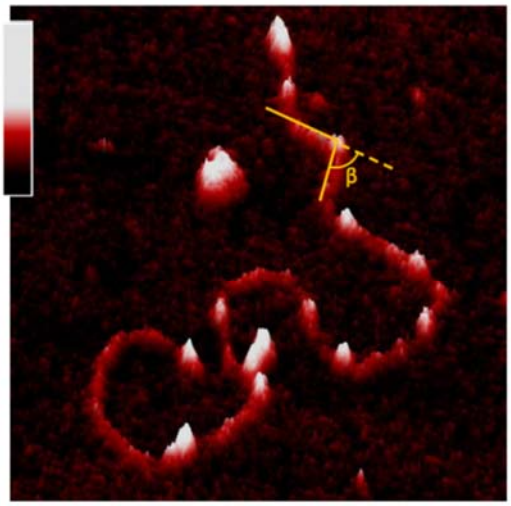
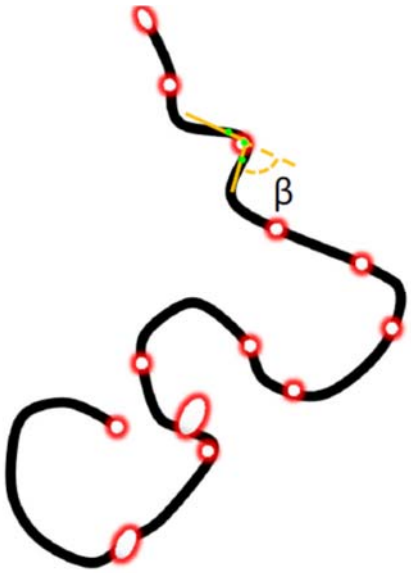
Vocabulary

Word	Definition	In a sentence

Homework





Measure the bending angle of DNA upon protein binding. Construct a distribution and discuss about the mean and the standard deviation.

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Tutorial 5 – How to interpret force-extension curve data

What is the Purpose of Tutorial 5?

- Understanding fits
- Understanding how to interpret data

Activity1: Worm-Like-Chain model (WLC)

$$b_{ds}(F) = B_{ds}\left[1-\frac{1}{2}\left(\frac{k_b T}{P_{ds} F}\right)^{1/2} + \frac{F}{S_{ds}}\right]$$

How many parameters are involved in fitting the equation above?

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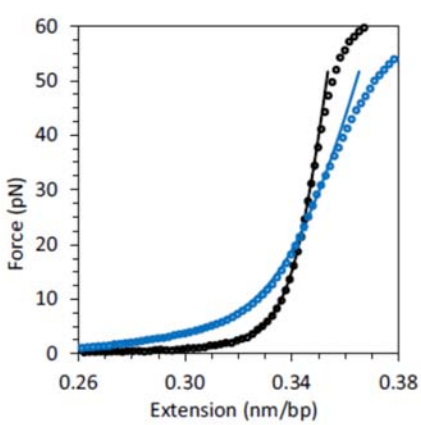
Activity2: Graphing the force-extension curve



Open an excel sheet and plot the equation? Use excel sheet and the (WLC) equation to fit the real data with and without proteins.

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Vocabulary

Word	Definition	In a sentence

Homework- Final assignment

In the final assignment you are going to write a scientific report. You will be using information covered in the tutorials, and as well as online research.

The title of your assignment is: “Single-molecule studies of DNA-protein interactions”.

For this assignment, you are going to do some online research and choose a protein which interacts with DNA. For the protein of your choice, explain and illustrate the biophysical methods used to investigate the interactions.

Your scientific report should be presented in paragraphs and arranged in a logical structure (max 2500 words and min 2000 words, approximately 4 to 5 pages). The report could include tables and graphs. The methods should be clearly structured. For the structure see my work online (please download the pdf version):
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4132745/

You should write in your own words. Do not copy and paste.
The introduction should clearly outline what the report will contain.
The conclusion should summarise all the key points.
Make sure that you have referenced everything correctly.
Make sure that your spelling, grammar and punctuation are accurate.

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…
•	•
•	•
•	•

My target for future work is…

Tutorial 7 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on final assignments.
- To share examples of best practice with the other pupils in your group.
- To write targets for improvement in school lessons.
- To reflect on the programme including what was enjoyed and what was challenging.

Final assignment feedback

What I did well…	What I could have improved on…
•	•
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•	•

My target for future work is…

Reflecting on Uni Pathways

What did you most enjoy about Uni Pathways?
• • •

What did you find challenging about the programme?	How did you overcome these challenges?
• • •	• • •

Appendix 1 – Referencing correctly

When you get to university, you will need to include references in the assignments that you write, so we would like you to start getting into the habit of referencing in your Brilliant Club assignment. This is really 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. In order to avoid losing marks in your final assignment, or even failing, you must be careful to reference your sources correctly.

What is a reference?

A reference is just a note in your assignment which says if you have referred to or been influenced by another source such as book, website or article. For example, if you use the internet to research a particular subject, and you want to include a specific piece of information from this website, you will need to reference it.

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 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.

How do I reference?

There are a number of different ways of referencing, and these often vary depending on what subject you are studying. The most important to thing is to be consistent. This means that you need to stick to the same system throughout your whole assignment. Here is a basic system of referencing that you can use, which consists of the following two parts:

1. **A marker in your assignment**: After you have used a reference in your assignment (you have read something and included it in your work as a quote, or re-written it your own words) you should mark this is in your text with a number, e.g. [1]. The next time you use a reference you should use the next number, e.g. [2].
2. **Bibliography**: This is just a list of the references you have used 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.

    a. **Websites** – Author (if possible), title of the web page, website address, [date you accessed it, in square brackets].

    E.g. Dan Snow, 'How did so many soldiers survive the trenches?', http://www.bbc.co.uk/guides/z3kgjxs#zg2dtfr [11 July 2014].

    b. **Books** – Author, date published, title of book (in italics), pages where the information came from.

    E.g. S. Dubner and S. Levitt, (2006) *Freakonomics*, 7-9.

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

    E.g. Maev Kennedy, 'The lights to go out across the UK to mark First World War's centenary', Guardian, 10 July 2014.

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Stretching DNA with tweezers made of light

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