Searching for SQUIDS – A Journey through High Temperature Superconductivity

Key Stage 4 Programme – 2016-2017

Teacher Name Dr Jacqui Edwards

Pupil Name_____

Timetable and Assignment Submission

Fill this in with your teacher.

Timetable – Tutorials

Tutorial	Date	Time	Location
1			
2			
3			
4			
5			
6			

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 4.00pm on	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

KS4 Programme 2016-17 – Pupil Feedback Report

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at GCSE +
2:1	60-69	Performing to a good standard at GCSE
2:2	50-59	Performing to an excellent standard at Year 10
3rd	40-49	Performing to a good standard at Year 10
Working towards a pass	0-39	Performing below a good standard at Year 10
Did not submit	DNS	No assignment received

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

Name of RIS Teacher	Dr Jacqui Edwards		
Title of Assignment			
Name of Pupil			
Name of School	Baylis Court School, Slough		
ORIGINAL MARK / 100		**FINAL MARK / 100**	
DEDUCTED MARKS		**FINAL GRADE**	

If marks have been deducted (e.g. late submission, plagiarism) the teacher should give an explanation in this section:

Learning Feedback Comment 1 - *Logical Reasoning*	
What you did in relation to this Key Learning Priority	**How you could improve in the future**
Learning Feedback Comment 2 – *Creativity*	
What you did in relation to this Key Learning Priority	**How you could improve in the future**
Learning Feedback Comment 3 – *Communication*	
What you did in relation to this Key Learning Priority	**How you could improve in the future**
Resilience Comment	
How you showed learning resilience during the course	**How you could build learning resilience in the future**

Searching for SQUIDS – A journey through High Temperature Superconductivity

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- How cold is cold?
- HTS Discovery – Quiz
- HTS Properties - Demo
- Cooper pairs - Video
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- Crystals – Odd one out
- Diffraction – Demo, Plotting Graphs
- HTS crystal – Build model
- Homework – Calculate the c lattice parameter of YBCO

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- How SQUIDS work - Video
- How we can use SQUIDs – Picture quiz
- HTS SQUIDs - Discussion
- Homework – Research nanotechnology

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- Key nanotech capabilities – Match with definitions
- How can nanotech change the world – Pair and share discussion
- Match key HTS problems with nanotech capabilities – Pairing exercise
- Homework – Draw mind map for research proposal

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- What do you think scientists do?
- Day in the life of a scientist - Video
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Course Rationale

This course is aimed at students who are interested in how to apply new scientific discoveries to make useful things. Superconductors are amazing materials which lose all resistance to electrical current when they are cooled to extremely low temperatures. The surprise discovery in the 1980's of 'high temperature' superconductors, which 'only' need to be cooled to about -200°C, resulted in one of the most rapid awards of a Nobel prize ever and a frenzy of activity from scientists eager to understand them and find uses for them in the real world. High temperature superconductors were quickly used to make and study tiny electrical devices called Josephson Junctions. Josephson Junctions are essential components of SQUIDs, which can be used to detect magnetic fields as small as the ones made by the electrical currents resulting from thoughts in your brain. However, it proved difficult to make them reliably from high temperature superconductors.

We will then fast forward to the present day to look at the exciting developments in the science of making extremely tiny things which have given birth to the new field of nanotechnology. Nanotechnology can use individual atoms to build the smallest possible manmade structures and has enormous potential to revolutionise science, engineering and medicine. We will revisit some of the mysteries of high temperature superconductors which still remain puzzles today and consider how nanotechnology might be used to investigate and solve them. At the end of the course students will use their learning to write a research proposal suggesting a new application of nanotechnology to high temperature superconductors.

Each tutorial will build on students' existing understanding of physics, chemistry and materials to explore:-

- new areas of science including the weird properties of superconductors,
- how to study and control the fascinating crystal structures of high temperature superconductors,
- how to make and measure really tiny Josephson Junctions
- the exciting new field of nanotechnology
- how scientists collaborate and work together.

Students will learn how to understand how high temperature superconductors fit into in their wider scientific context, build on their existing knowledge to understand fresh scientific concepts and will also have the opportunity to analyse and interpret real experimental data. In addition they will develop their creative problem solving skills and learn how to communicate effectively with other scientists.

Ideally once the proposals are written the course will be extended by visit to a cutting edge research institution, for example the London Centre for Nanotechnology, and it could also be extended by a visit from a guest speaker working in the fields of superconductivity or nanotech.

Course Map

High Temperature Superconductors
How Scientists Work Together
Crystal Structures
Write a research proposal suggesting a new application of Nanotechnology to High Temperature Superconductors
Nanotechnology
Superconducting SQUIDs

Mark Scheme

Key Skill	1st	2.2
Contextualising (Presentation of the topic relative to current work in the area. The significance or worthiness of context being explored).	☐ Current theories or work in the fields of superconductivity and/or nanotech are outlined, making it clear how the research proposal fits into that context ☐ Explains clearly why the subject of the research proposal is significant and worthy of discussion or investigation	☐ Some references are used, but more should be made to current theories or work in the fields of superconductivity/nanotech. More clarity could be achieved with how the research proposal fits into that context. ☐ Explanation is included of why the subject of the research proposal is significant and worthy of discussion, but it could be more clearly explained.
Application (Recognise, recall and show understanding of content knowledge).	☐ Makes new links between subjects (for example superconductivity and nanotechnology) that have not previously been associated in the tutorials. ☐ Confidently uses concepts such as superconductivity and diffraction from above their current key stage (KS4).	☐ When directed, applies concepts from tutorials to unfamiliar situations reasonably accurately. ☐ Confidently uses the concepts from their current key stage (KS4), but may struggle with new concepts (eg superconductivity and diffraction) introduced in the tutorials that are at the key stage above current level.
Logical Reasoning (Coherence and clarity of the logical argument).	☐ There is a clear and structured flow of argument when using logical reasoning to explain, for example, why a particular capability of nanotechnology could solve a particular problem in superconductivity . ☐ Arguments and reasoning are expressed with clarity towards an end goal or conclusion.	☐ Arguments are generally structured and well explained, however in places they may be unclear and difficult to follow. ☐ Sometimes clarity within arguments and reasoning towards the end goal or conclusion could be improved.
Creativity (Uniqueness and level of depth of the work).	☐ High levels of intellectual initiative, insight, and creativity, for example, in proposing a completely new yet feasible experiment or application. ☐ Unique opinions, arguments, or conclusions are made.	☐ Evidence of creative qualities, however ideally the topic would be explored in more depth. ☐ Effort has been made to approach the topic from a unique angle, but it could be approached with better scientific explanations.
Communication (Quality of written communication, including presentation and structure).	☐ Writing is coherent and organised following a logical sequence, with effective of use of appropriate new scientific vocabulary. ☐ Writing is grammatically correct and of an appropriate style for the document. ☐ Effective use of pictures, graphs and diagrams when appropriate, when, for example, to show a crystal structure or explain a nanodevice.	☐ At times the organisation and coherence of the writing and use of appropriate new scientific vocabulary could be increased. ☐ Clarity could be improved by more consistent use of style and grammar throughout ☐ More use could be made of pictures, graphs and diagrams.

Glossary of Keywords

Word	Definition	In a sentence…
Superconductor	A super conductor is a material which has exactly zero resistance and expels all magnetic fields below a temperature called its critical temperature. The critical temperatures of 'normal' superconductors are is typically between 0K to 25K (-273°C to -248°C), very much colder than room temperature.	The first superconductor (solid mercury) was discovered in 1911 by a Dutch scientist, Heike Kamerlingh Onnes, and had a critical temperature of 4.2K (-268.8°C).
High Temperature Superconductor	A high temperature superconductor is a superconductor which typically has a critical temperature above about 77K (-196°C), which is still very cold!	High temperature superconductors were discovered in 1986 by two Swiss scientists, Georg Bednorz and Alex Muller – they received the Nobel prize for their discovery the year after, in 1987.
Quantum Mechanics	A branch of physics which deals with the structure and behaviour of very small particles of matter (eg photons, electrons, protons) by describing them as having some of the characteristics of waves.	The properties of superconductors can only be explained by using quantum mechanics.
Cooper Pairs	A pair of electrons in a superconducting material that are weakly attracted and bound to each other by their interactions with the superconductor's crystal lattice, even though the electrons are repelled by each other as they both have negative charge.	Superconductors' properties are explained by the formation of quantum mechanical Cooper pairs below the superconductor's critical temperature.
Crystal	A crystal is a solid whose building blocks (for example atoms, molecules or ions) are arranged in a highly ordered microscopic structure, forming a crystal lattice that extends in all directions.	High temperature superconductors have complex crystal lattices, which cause their high critical temperatures.
Diffraction	Diffraction happens when a wave encounters an obstacle or a slit. The wave bends around the corners of the obstacle or slit into the region of its geometric shadow. Diffraction occurs with all waves, including sound, water, light and electrons, since according to quantum mechanics, electrons have some of the properties of waves.	X-ray diffraction is used to study the lattice structures of many types of crystals, including high temperature superconductors.
Bragg's Law	Bragg's law provides the mathematical condition for an incident wave to be diffracted by a crystal lattice $2d \sin \theta = n \lambda$, where d is the lattice spacing, θ (theta) is the angle between the direction of travel of the incident wave and the lattice plane, n is an integer, and λ (lambda) is the wavelength of the incident wave.	Bragg's law can be used to measure the distance between lattice planes in many types of crystals including high temperature superconductors.
Josephson Junction	A Josephson Junction consists of two superconductors coupled by a weak link - an insulator, a non-superconducting metal or a constriction. Cooper pairs can pass (tunnel) across the junction even when no voltage is applied – this is the (d.c.) Josephson effect.	The British physicist Brian Josephson predicted the Josephson effect in 1962 and was subsequently awarded the Nobel prize for physics for his work in 1973.
SQUID	SQUID stands for Superconducting Quantum Interference Device. A SQUID is made from a loop of superconducting material which includes two Josephson Junctions.	SQUIDs can be used to detect tiny changes in magnetic fields, such as subtle changes in the human body's electromagnetic energy field.
Nanotechnology	Nanotechnology is the branch of technology that deals with dimensions of less than 100 nanometres, especially the manipulation of individual atoms and molecules.	Nanotechnology has the potential to solve some of the challenges still facing the study and use of high temperature superconductors today.
Research	Creative work undertaken on a systematic basis in order to establish or confirm facts, reaffirm the results of previous work, solve new or existing problems, support theorems or develop new theories, and the use of this stock of knowledge to devise new applications.	Scientists are still researching many aspects of high temperature superconductivity - for example, exactly how it works and how to make room temperature superconductors.
Research Proposal	A research proposal is a document proposing a research project and generally constitutes a request for sponsorship of that project.	Research proposals are evaluated on the cost and potential impact of the proposed research and on the soundness of the proposed plan for carrying it out.

Tutorial 1 – High Temperature Superconductors

Today's Key Question(s):

- What are High Temperature Superconductors (HTS's)?
- Why are High Temperature Superconductors so special?
- How can we explain how they behave?

What is the Purpose of Tutorial 1?

- Introduce myself and the course
- Learn the key properties of High Temperature Superconductors (HTS's)
- Appreciate why their discovery was so exciting
- Understand how quantum mechanics helps explain how HTS's behave

Today's Homework is:

- Baseline Assessment – Compare the electrical properties of normal metals and superconductors when you cool them down to very low temperatures.

Homework 1 – Baseline Test

The homework assignment for the first tutorial is a baseline test to see your initial level of attainment in this subject area. The assignment will test for some or all of the subject specific skills that are required later in the final assignment. However, it is shorter than the final assignment and is will be an introduction to the subject as well as a challenge!

Do not worry too much about doing 'well' or 'badly' on the baseline test, it takes into account the fact that you may not be familiar with the subject area. It is designed to help you and your PhD tutor identify where you are at the start of the programme and to help you measure your progress along the way.

Essay – How normal metals and superconductors behave differently at low temperatures

Write a short structured essay comparing how a 'normal' metal and a superconducting metal conduct electrical currents at very low temperatures, below the critical temperature of the superconductor. Include labelled diagrams showing how the metal atoms are arranged and how the electrons move through them in both cases.

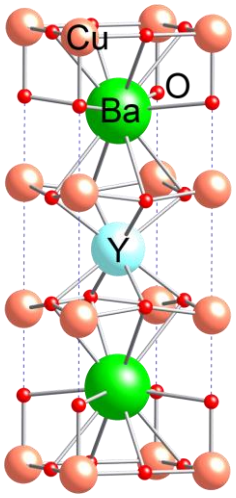
Describe what happens to the flow of electrons in the normal metal and the superconductor when the temperature gets hotter, above the critical temperature of the superconductor. Why does this happen? Sketch some graphs of how the resistance of the two materials changes with temperature.

Suggest some possible uses for superconducting materials and explain why it would be much easier to use them if they were superconducting at room temperatures.

Guidance will be given with the essay structure – for example Title/Context/Comparison/Applications

Suggested word limit 1000 words (not including diagrams).

Tutorial 2 – Crystal Structures



Today's Key Question(s):

- What are crystals?
- How do we study them?
- What is the crystal structure of High Temperature Superconductors?
- Why is it important to grow single crystals of High Temperature Superconductors?

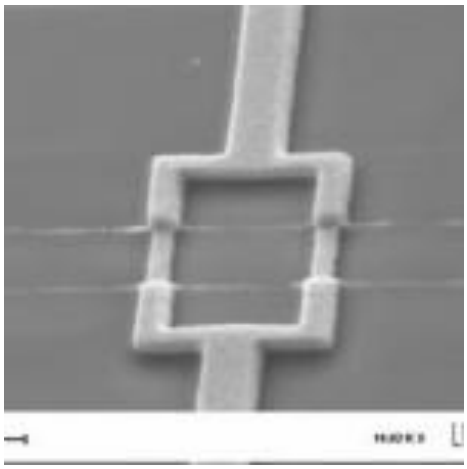
What is the Purpose of Tutorial 2?

- To revise crystal structures and learn about X-ray diffraction and Bragg's law
- Understand the crystal structure of a famous High Temperature Superconductor, YBa2Cu3O7 and how it is related to its properties

Today's Homework is:

- Using the supplied handout, work out the 'c' lattice parameters of two different films of high temperature superconductors from their diffraction patterns. Use the value of the c lattice parameter to predict which thin film is more suitable to make a good quality High Temperature Superconducting device.

Tutorial 3 – Superconducting SQUIDs



Today's Key Question(s):

- What is a superconducting SQUID and how does it work?
- Why are superconducting SQUIDs so useful?
- How do we make a SQUID using High Temperature Superconductors and why is it so difficult?

What is the Purpose of Tutorial 3?

- To learn what superconducting SQUIDS are, how they work, and how we can use them.
- To understand how High Temperature Superconductors can be used to make useful devices such as SQUIDs
- To gain an understanding of how to make small superconducting devices and the issue of reproducibility

Today's Homework is:

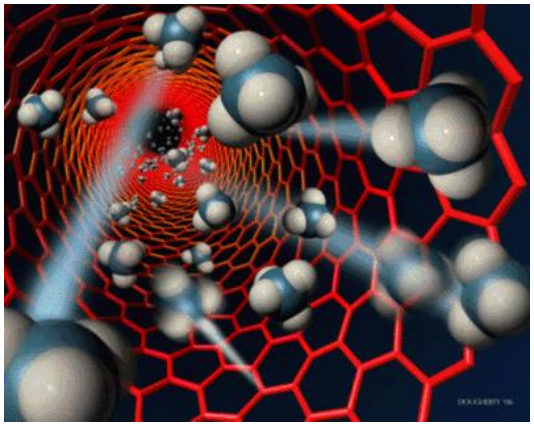
Watch the Nanotech video "How will Nanotechnology Change the World" or similar

https://www.youtube.com/watch?v=cG9P8DLuh0U

As you watch summarise what you think nanotechnology is and make a note of some of the ways that nanotechnology might change our everyday lives.

Optionally students could extend this topic via independent research.

Tutorial 4 – Nanotechnology



Today's Key Question(s):

- What is nanotechnology and how might it change the world?
- What are the key unsolved problems in High Temperature Superconductivity?
- How could nanotechnology be used to solve them?

What is the Purpose of Tutorial 4?

- Learn more about nanotechnology
- Consider how new nanotech techniques might solve High Temperature Superconducting problems

Today's Homework is:

Mind map for Final Assignment

Suggest how a new nanotech technique might help study or solve an unsolved High Temperature Superconducting problem. Look at the supplied outline research proposal and for your suggestion, draft a mind map and research where you might find the information for each section. You will use this mind map to plan your final assignment.

Tutorial 5 – How Scientists Work Together

Today's Key Questions:

- How do scientists work together?
- How do they choose which new research to do?
- What makes a good research proposal?

What is the Purpose of Tutorial 5?

- Understand in more depth how scientists and engineers work together and new research is chosen
- Gain an appreciation of potential activities and careers in the research environment
- Prepare for the final assignment

Today's Homework is:

- Final Assignment

Write a research proposal suggesting a new application of nanotechnology to high temperature superconductors

Provisionally, the research proposal should be structured as follows:-

- Title
- Abstract
- Research Context
- Research Questions
- Research Methods
- Significance of Research
- Bibliography

See for example http://www.birmingham.ac.uk/schools/law/courses/research/research-proposal.aspx. It's how to write a law research proposal but the same principles apply for science!

A limit of 2000 words is suggested.

The Deadline is:

Tutorial 6 – Feedback

What is the Purpose of Tutorial 6?

- Reflect on skills learned on the programme with a view to encouraging resilience
- Receive feedback on final assignment

What are the key questions?

- What strengths have I demonstrated in my work and what areas of development are there left for me to address?
- What steps do I need to take to improve my academic output?

Activity 1 – Marking your own

Using the mark scheme, identify three things you did well and three things you could improve.

What went well?

1.

2.

3.

What could be improved?

1.

2.

3.

Activity 2 – Responding to feedback

Read through your feedback sheet and highlight on your assignment where you received positive feedback (one colour) and areas for improvement (different colour). You might find it helpful to annotate this with a brief comment or two.

Activity 3 – Looking Forwards: Think, Pair Share

1. Think about how you can use this feedback in your future school work.
2. Talk to your partner about how you both plan to make changes to your school work in the future as result of this feedback
3. Share your ideas as a group.

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:

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].

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.

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].

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.

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.

Appendix 2 – University Applications Guidance

For course choices and careers information:	www.brightknowledge.org.uk
For information and statistics on universities and course:	www.unistats.direct.gov.uk
For comprehensive information on universities, including rankings:	www.thecompleteuniversityguide.co.uk

PLEASE NOTE – The Researchers in Schools programme is designed to support the university applications process at your school. The work you complete for the programme should add to your schoolwork rather than detract from it. Please be aware of deadlines and try to manage your workload appropriately. If you are worried about the programme interfering with your schoolwork then please speak to your teacher.

Science Specific Top Tips for Strengthening an Application.

Universities are looking for :-

- **Academic Skill and Potential**
- **Enthusiasm for Subject**
- **Motivation to Study Independently**
- **Suitability and Base Knowledge**

Top Tip 1 - Do the best you can in your GCSE's and A-levels!

You will find that as well as learning as much as possible from your lessons and textbooks, keeping an active interest in scientific discoveries and researching around your subject will help you with this.

Top Tip 2 - Research around your subject!

Keep up to date with scientific discoveries – Radio/TV/Internet news/BBC Click are all good sources of information

Try reading magazines – New Scientist / Scientific American / The Economist (science section)

Look in the school or your local library for science books and publications.

Try reading some science fiction – H.G. Wells (The War of the Worlds, The Time Machine), John Wyndham (The Crysalids), Isaac Asimov (I, Robot), Arthur C. Clarke (Rendezvous with Rama, The City and the Stars) and Philip K. Dick (Do Androids Dream of Electric Sheep?) are all classics. Or try watching some Sci –Fi films – eg Apollo 13 (PG), Gravity (PG-13), The Martian (PG-13).

There are some fantastic resources on the Internet! Try for a start:-

Wikipedia (usually excellent overviews/introductions to a subject)

https://www.youtube.com/user/Kurzgesagt

https://www.youtube.com/user/minutephysics/videos

https://www.youtube.com/user/minuteearth

Top Tip 3 – Visit a Science Museum or Science Festival!

Suggestions are – the Science Museum, Natural History Museum, Winchester Science Centre (this last is great for hands on)

http://www.winchestersciencecentre.org/

Cheltenham Science Festival – 6 – 11th June 2017 – brilliant!

http://www.cheltenhamfestivals.com/science/

Top Tip 4 – Attend a University Open Day, Summer School, Take Part in a Mentoring Scheme or Get Relevant Work Experience!

For example (and this is only a start!)

For girls who want to be scientists or engineers (these courses are largely suitable for both):-

http://www.wes.org.uk/content/engineering-summer-schools

Year 10 – Imperial Summer School

http://www3.imperial.ac.uk/newsandeventspggrp/imperialcollege/administration/outreach/eventssummary/event_18-12-2012-13-51-41

Year 11 – Summer Work Experience

Ask your careers advisors!

Year 12 – Nuffield Research Placements

http://www.nuffieldfoundation.org/nuffield-research-placements

Year 12 – Sutton Trust Summer Schools

http://www.suttontrust.com/about-us/faqs/summer-schools/

Year 12 – Oxford Summer Schools

http://www.uniq.ox.ac.uk/

Year 12 – UCL Summer Schools

https://www.ucl.ac.uk/prospective-students/widening-participation/activities/summer-schools

Year 12/13 – Kings College Summer Schools

http://www.kcl.ac.uk/study/summer/summer-schools/pre-university/about.aspx