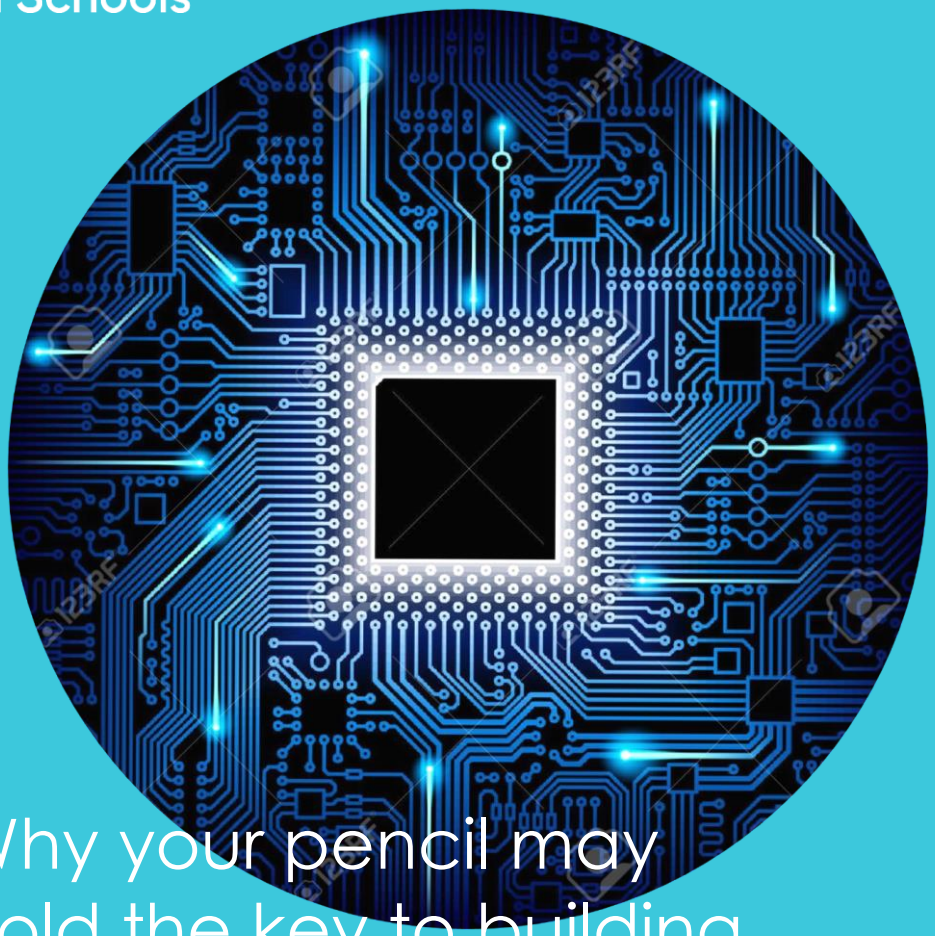
Researchers in Schools



Why your pencil may hold the key to building computers of the future.

Key Stage 4 Programme

Pupil Name	
Coursebook Designed by	Dr. J. J. van den Berg

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Uni Pathways launch event

Welcome to Uni Pathways! We are delighted to be able to launch the Uni Pathways programme with you. We hope that you are ready to embark on your Uni Pathways journey and that you enjoy the video.
You will be asked to pause the video at times to complete some work in this workbook, so make sure you have a pen / pencil to hand when you start the video.

By the end of the video, you will have

- Learnt about what studying at university means
- Learnt about some of the skills that you will develop during Uni Pathways
- Heard from pupils who have participated in Uni Pathways or The Scholars Programme (which is the same programme!)
- Heard from current university students talking about what life is like at university

If you are in school your teacher will play the video. If you are at home and logged in to a session with your teacher, your teacher will play the video and show it to you. If you are participating independently your teacher will email you the link to the video or the video file. There are opportunities for you to answer some questions, and you will be told when to pause the video to answer them.

Introduction to Uni Pathways

1. Write down what you think a supra-activity is

_____
_____
_____

2. Independent learning is

_____
_____
_____

3. Write down in your own words what resilience means, and come up with a different example to the one mentioned in the PowerPoint.

_____
_____
_____
_____

4. Why do you think analysis and evaluation skills are useful in your academic career?

_____
_____
_____
_____
_____

5. Why do you think analysis and evaluation skills are useful in life in general?

_____
_____
_____
_____
_____

6. What are the different types of learning that university students do?

Pupils' experience of Uni Pathways

You will now watch some pupils talk about their experience of learning a PhD topic and producing a final assignment. Some may refer to The Scholars Programme rather than Uni Pathways. As you heard in the introduction PowerPoint, The Scholars Programme is a very similar programme to Uni Pathways. Listen carefully and then respond to the questions below. Be prepared to share some of your responses with your peers.

1. How did the pupils describe talking about writing a long essay for their final assignment?

2. Write down something that one of the pupils mentioned was particularly interesting in their course.

3. What were some challenges that the pupils met?

Virtual campus tours

You will now go on a virtual tour of some universities! Once you have seen some of the university campuses, respond to the questions below.
Note down something that you liked out of any of the campus tours you saw. It may be a particular building, space, city etc.

1. Were there any similarities between the different university campuses? If so, what are the similarities?

2. If you had to pick one of those universities to go and visit in person, which one would it be and why?

3. Note down some of the societies that you could join at different universities

Meet university students!

You are about to virtually meet or hear from some current university students.
If you are virtually meeting them, think about what questions you would like to ask the students, share your questions with a partner and note those questions down in the space below.

If you are not meeting them but watching some videos that they have made, use the space below to note down what else you would like to find out about university. You can then ask your teacher during Uni Pathways tutorials!

Reflection

Congratulations on completing the launch of the Uni Pathways programme. Before you go, take some time to reflect on what you have learnt by answering the following questions:

1. Are there any aspects of university style learning that you would look forward to? If so, what are they?

2. What challenges do you think students face when learning at university? How would you try to overcome these challenges?

3. What skills do you hope to develop during your Uni Pathways course?

4. What part of Uni Pathways seems the most challenging for you?

5. What are you most looking forward to about Uni Pathways?

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	Baseline assignment: Why do scientists consider graphene to be a 'wonder material'?	
Tutorial 2	Homework assignment Tutorial 2: What questions might you ask to improve your understanding about Moore's law?	
Tutorial 3	Homework assignment Tutorial 3: How would you explain quantum mechanics to your parents or friends?	
Tutorial 4	Homework assignment Tutorial 4: Which concepts in spintronics did you find difficult?	
Tutorial 5	Final assignment: What are the promises and challenges of graphene as a spintronic material in computer chips of the future?	

Commented [CH1]: Can you give all of these homeworks a title? What does the homework cover? For example, your baseline is "Why do scientists consider graphene to be a 'wonder material'?"

Assignment Submission – Lateness and Plagiarism

Lateness	
Submission after midnight on due date	10 marks deducted
Plagiarism	
Some plagiarism	10 marks deducted
Moderate plagiarism	20 marks deducted
Extreme plagiarism	Automatic fail

Course Rationale

Why your pencil may hold the key to building computers of the future

Did you know that you can use your pencil to make graphene, a material so flat that it is just one atom thick? In this course, you will learn how to make graphene and why its discovery was worthy of the Nobel prize in Physics.

The discovery of new materials has enabled us to develop new technology throughout history. Materials and techniques to make silicon chips have been improving rapidly during the last few decades. As a result, your smartphone has massively more computer power than the fastest supercomputers of 40 years ago.

Is this trend of faster and smaller computers going to continue in the future? We cannot be certain, but during this course you will learn about some of the challenges scientists and engineers need to address to make that happen.

This is where the new material graphene comes in. Graphene, the thinnest material possible, has new and exciting properties no material before it has ever had. During this course, you will learn why a graphene wire can conduct a magnetised current better than any other material. You will be able to explain that this wire is a spintronic circuit (short for spin-electronic) and why spintronic materials may be an important building block for future computer chips.

By the end of the course, you will write an essay about graphene spintronics and explain what problems should be solved to make this future application a success.

Uni Pathways Mark Scheme 2020 – Science-based assignments

	Subject Knowledge	Critical Thinking	Written Communication
1st	The work shows a depth of knowledge and understanding of key concepts and scientific methods, through engaging with relevant sources. Knowledge is used to build and support highly effective scientific arguments and explanations.	Analyses key scientific evidence, arguments, and reasoning. Interprets meaning and makes connections. Identifies and critically evaluates key scientific arguments and evidence, deciding on their credibility, strength, and relative significance, drawing convincing conclusions.	The work has a coherent flow and is well structured. The writing style is appropriate; scientific language and key scientific terms are used accurately and effectively to support the arguments and explanations made. There are no, or very few, errors in spelling or grammar. Consistent referencing, appropriate paragraphing and use of correctly labelled tables and graphs matching the style taught in the course.
2:1	The work shows an understanding of key concepts and scientific methods, drawing on relevant sources. Knowledge is used to build and support effective scientific arguments and explanations.	Analyses relevant scientific evidence, arguments, and reasoning. Identifies and critically evaluates relevant scientific arguments and evidence, deciding on their credibility and strength, drawing reasonable conclusions. Shows some understanding of the relative value of evidence and arguments.	The work is well-structured. The writing style is appropriate; scientific language and key terms are used correctly. There are few errors in spelling or grammar. Mostly consistent referencing and use of tables and figures; matching the style taught in the course.
2:2	The work shows an understanding of key concepts and scientific methods, with no major misconceptions. Beginning to apply this knowledge to build and support effective scientific arguments and explanations.	Identifies and uses basic scientific evidence, arguments, and reasoning. Showing some understanding of the quality of scientific arguments and evidence. Not yet showing understanding of the relative value of evidence and arguments.	The work has some structure. The writing style can sometimes be informal; occasionally scientific language and key terms are not used when it would be appropriate to do so. There are some errors in grammar and spelling do not get in the way of communicating the content. Referencing has some consistency; matching the style taught in the course Limited use of tables and graphs.
3rd	Shows a developing understanding of key concepts and scientific methods, with some misconceptions. Does not yet apply this knowledge to build and support scientific arguments and explanations.	Beginning to analyse scientific evidence, arguments, and reasoning. Describes evidence and arguments, while not yet evaluating them.	The grammar, spelling, style, and structure of the work need improving in order to communicate ideas to the reader. Scientific language, key terms and references are not always used correctly. Limited, or no use of tables and graphs.

Baseline Assignment (essay based): Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	
Title of Assignment	

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
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

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

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

Mark Breakdown and Feedback

Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Final Assignment (essay based): Pupil Feedback Report

Name of Pupil	
Name of School	
Name of RIS teacher	
Title of Assignment	

How your assignment is graded:

Grade	Marks	What this means
1st	70+	Performing to an excellent standard at A-level
2:1	60-69	Performing to a good standard at A-level
2:2	50-59	Performing to an excellent standard at GCSE
3rd	40-49	Performing to a good standard at GCSE
Working towards a pass	0-39	Performing below a good standard at GCSE
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

Marks

OVERALL MARK / 100		FINAL MARK / 100 (including any deductions)	
DEDUCTED MARKS		FINAL GRADE	

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

Mark Breakdown and Feedback

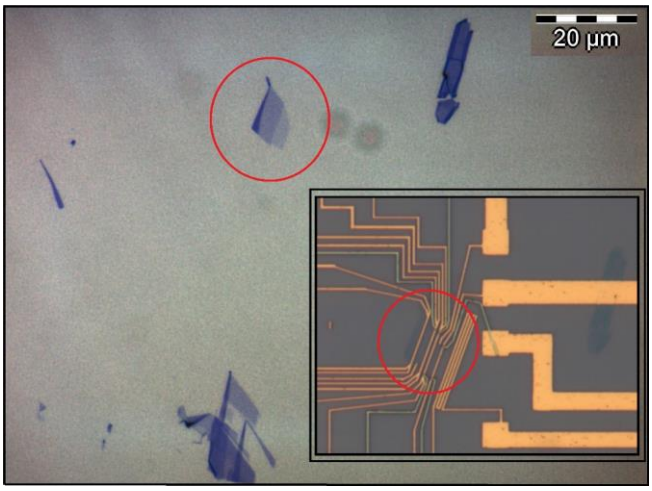
Subject knowledge	
	mark
Critical thinking	
	mark
Written communication	
	mark

Subject Vocabulary

Word	Definition	In a sentence
Bit	Short for binary digit, the smallest way in which information is stored and handled inside computers. A bit can usually have one of two values: 0 or 1.	
Electron	A particle present in every atom. In an electrically conducting material such as a metal, some electrons of its atoms can move about freely.	
Exfoliation	The removal of thin layers. This relates to the verb exfoliate – to remove thin layers.	
Graphene	A very thin material made of one layer of carbon atoms.	
Logic Operation	The simplest calculation a computer can make. Many logic operations are used together inside a computer to form more complex calculations.	
Magnetisation	1. The process that makes a material magnetic. This relates to the verb magnetise – to make a material magnetic. 2. A quantity that describes how strongly magnetic a material is.	Example for meaning 1: Example for meaning 2:
Moore's law	The observation that the number of transistors on computer chips doubles about every two years.	
Nanotechnology	Technology to make structures so small, that their size is typically measured in nanometres.	

Quantum mechanics	The laws of physics describing that nature works fundamentally different at the scale of atoms and particles.	
Spin	The quantum-mechanical property of elementary particles such as electrons which makes them behave like tiny magnets.	
Spin current (or: spin-polarised current)	A current which is magnetised because the number of spin-up and spin-down electrons is imbalanced.	
Spin relaxation length	The distance over which a spin current can travel before spin relaxation takes place and the spin polarisation of the current is lost. It is a material-dependent property.	
Spintronics	Short for spin electronics. Spintronic circuits are circuits which make use of the fact that electrons have spin, for instance to carry information.	
Transistor	A small electronic switch which is used as the main building block of computer chips. Switching a transistor between ON and OFF can be used to keep track of the 1s and 0s that computers use for their calculations.	
Two-Dimensional (2D) material	A material consisting of a single layer of atoms. For such a material, all the atoms are on the material's surface.	

Tutorial 1 – Graphene: The discovery of the world's thinnest material.

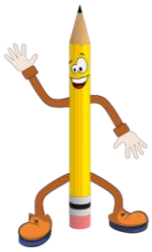


What is the Purpose of Tutorial 1?

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

- Describe the structure of graphene and some of its properties.
- Select three examples of exciting properties and/or uses of graphene.
- Argue whether a use or application is interesting from a scientific and/or practical application point of view.

Activity 1 – How to make graphene?



Based on the introduction slides about graphene, develop a 3-step recipe to create graphene using graphite, scotch tape and a substrate (the substrate is paper).

Hints:

- What is graphene's structure?
- How would you isolate such a structure using the provided materials?

Recipe for the fabrication of graphene

Step 1:

Step 2:

Step 3:

Activity 2 – Carbon wonderland

Read the following excerpts from Scientific American and answer the questions that follow. After completing the questions, be prepared to share you answers with the whole class in a group discussion.

Consider the humble pencil. It may come as a surprise to learn that the now common writing instrument at one time topped the list of must-have, high-tech gadgets. In fact, the simple pencil was once even banned from export as a strategic military asset. But what is probably more unexpected is the news that every time someone scribes a line with a pencil, the resulting mark includes bits of the hottest new material in physics and nanotechnology: graphene.

Graphene comes from graphite, the "lead" in a pencil: a kind of pure carbon formed from flat, stacked layers of atoms. The tiered structure of graphite was discerned centuries ago, and so it was natural for physicists and materials scientists to try splitting the mineral into its constituent sheets—if only to study a substance whose geometry might turn out to be so elegantly simple. Graphene is the name given to one such sheet. It is made up entirely of carbon atoms bound together in a network of repeating hexagons within a single plane just one atom thick.

[..]

The experimental discovery of graphene led to a deluge of international research interest. Not only is it the thinnest of all possible materials, it is also extremely strong and stiff. Moreover, in its pure form it conducts electrons faster at room temperature than any other substance. Engineers at laboratories worldwide are currently scrutinizing the stuff to determine whether it can be fabricated into products such as super tough composites, smart displays, ultrafast transistors and quantum-dot computers.

In the meantime, the peculiar nature of graphene at the atomic scale is enabling physicists to delve into phenomena that must be described by relativistic quantum physics. Investigating such phenomena, some of the most exotic in nature, has heretofore been the exclusive preserve of astrophysicists and high-energy particle physicists working with multimillion-dollar telescopes or multibillion-dollar particle accelerators. Graphene makes it possible for experimenters to test the predictions of relativistic quantum mechanics with laboratory benchtop apparatus.

[..]

Exceptional Exception

Two features of graphene make it an exceptional material. First, despite the relatively crude ways it is still being made, graphene exhibits remarkably high quality—resulting from a combination of the purity of its carbon content and the orderliness of the lattice into which its carbon atoms are arranged. Investigators have so far failed to find a single atomic defect in graphene—say, a vacancy at some atomic position in the lattice or an atom out of place. That perfect crystalline order seems to stem from the strong yet highly flexible interatomic bonds, which create a substance harder than diamond yet allow the planes to bend when mechanical force is applied. The flexibility enables the structure to accommodate a good deal of deformation before its atoms must reshuffle to adjust to the strain.

The quality of its crystal lattice is also responsible for the remarkably high electrical conductivity of graphene. Its electrons can travel without being scattered off course by lattice imperfections and foreign atoms. Even the jostling from the surrounding carbon atoms, which electrons in graphene must endure at room temperature, is relatively small because of the high strength of the interatomic bonds.
The second exceptional feature of graphene is that its conduction electrons, besides traveling largely unimpeded through the lattice, move much faster and as if they had far less mass than do the electrons that wander about through ordinary metals and semiconductors. Indeed, the electrons in graphene—perhaps "electric charge carriers" is a more appropriate term—are curious creatures that live in the weird world where rules analogous to those of relativistic quantum mechanics play an important role. That kind of interaction inside a solid, so far as anyone knows, is unique to graphene. Thanks to this novel material from a pencil, relativistic quantum mechanics is no longer confined to cosmology or high-energy physics; it has now entered the laboratory. [..]

Reprieve for Moore's Law?
One engineering direction deserves special mention: graphene-based electronics. We have emphasized that the charge carriers in graphene move at high speed and lose relatively little energy to scattering, or colliding, with atoms in its crystal lattice. That property should make it possible to build so-called ballistic transistors, ultrahigh-frequency devices that would respond much more quickly than existing transistors do.
Even more tantalizing is the possibility that graphene could help the microelectronics industry prolong the life of Moore's law. Gordon Moore, a pioneer of the electronics industry, pointed out some 40 years ago that the number of transistors that can be squeezed onto a given area doubles roughly every 18 months. The inevitable end of that continuing miniaturization has been prematurely announced many times.
The remarkable stability and electrical conductivity of graphene even at nanometer scales could enable the manufacture of individual transistors substantially less than 10 nanometers across and perhaps even as small as a single benzene ring. In the long run, one can envision entire integrated circuits carved out of a single graphene sheet. Whatever the future brings, the one-atomthick wonderland will almost certainly remain in the limelight for decades to come. Engineers will continue to work to bring its innovative byproducts to market, and physicists will continue to test its exotic quantum properties. But what is truly astonishing is the realization that all this richness and complexity had for centuries lain hidden in nearly every ordinary pencil mark.

Reference:
Carbon wonderland
Andre K Geim 1, Philip Kim
Sci Am. 2008 Apr;298(4):90-7. doi: 10.1038/scientificamerican0408-90.

Read the full paper at:
www.condmat.physics.manchester.ac.uk/pdf/mesoscopic/publications/graphene/SciAm_2008.pdf

KEY CONCEPTS

■ Graphene is a one-atomthick sheet of carbon that stacks with other such sheets to form graphite — pencil "lead." Physicists have only recently isolated the material.

■ The pure, flawless crystal conducts electricity faster at room temperature than any other substance.

■ Engineers envision a range of products made of graphene, such as ultrahigh-speed transistors. Physicists are finding the material enables them to test a theory of exotic phenomena previously thought to be observable only in black holes and high-energy particle accelerators.

Questions

a) The article states "The tiered structure of graphite was discerned centuries ago". Explain what is meant by a tiered structure and how the structure of graphite relates to the structure of graphene.

b) Name three properties of graphene.

1.

2.

3.

c) Name three ways graphene could potentially be useful.

1.

2.

3.

d) Explain in your own words the difference between a property and an application.

e) For each of your answers under c), explain whether the use you have found is interesting from a scientific point-of-view, and why. To strengthen your argument, use examples from the article excerpt.

1.

2.

3.

f) For each of your answers under c), explain whether the use you have found is a good practical application and why. To strengthen your argument, use examples from the article excerpt.

1.

2.

3.

g) Think of at least one potential use that is not described in the article. Your example(s) can be a scientific use, a practical application, or both.

Tutorial 1 Notes

Baseline assignment

Write a 500 words (+/- 10%) essay in which you answer the following question:

Why do scientists consider graphene to be a 'wonder material'?

Success criteria.

Your essay should address the following points:

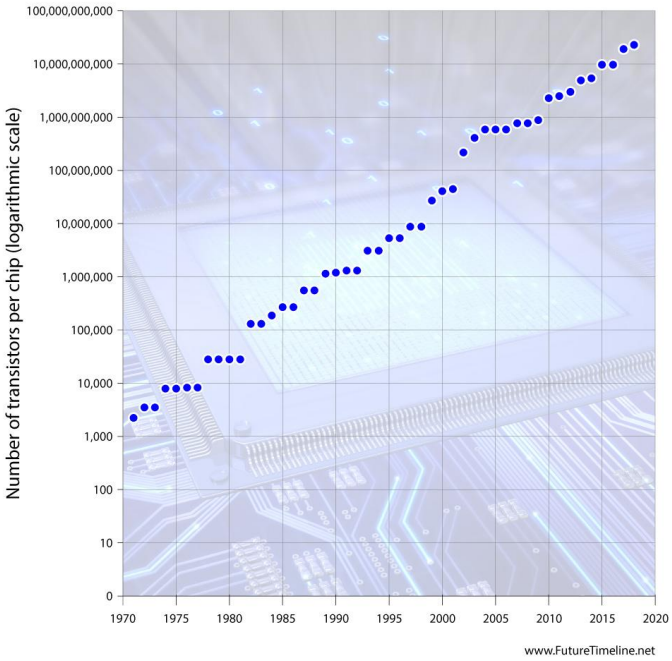
- What is graphene and how is it made?
  - Describe the structure of graphene.
  - Describe at least three properties of graphene
  - Describe how graphene can be made.
- The importance of the discovery of graphene.
  - Describe at least two characteristics of graphene that are unique compared to existing materials.
  - Argue why graphene is interesting scientifically.
  - Evaluate for at least two applications of graphene why they are useful.
- Your own opinion about graphene
  - Describe which aspect of graphene you find most interesting and defend your opinion.

Furthermore, your essay should meet the following criteria:

- Correct use of grammar and spelling,
- Follow a clear structure, for example:
  - Introduction paragraph.
  - Paragraph about the properties of graphene.
  - Paragraph about the significance of graphene's discovery.
  - Conclusion paragraph.

  Note: an alternative structure, for instance with a different number of paragraphs, is allowed.
- Use of scientific language and keywords.
- Compelling title.

Tutorial 2 – Electronics on the nanoscale



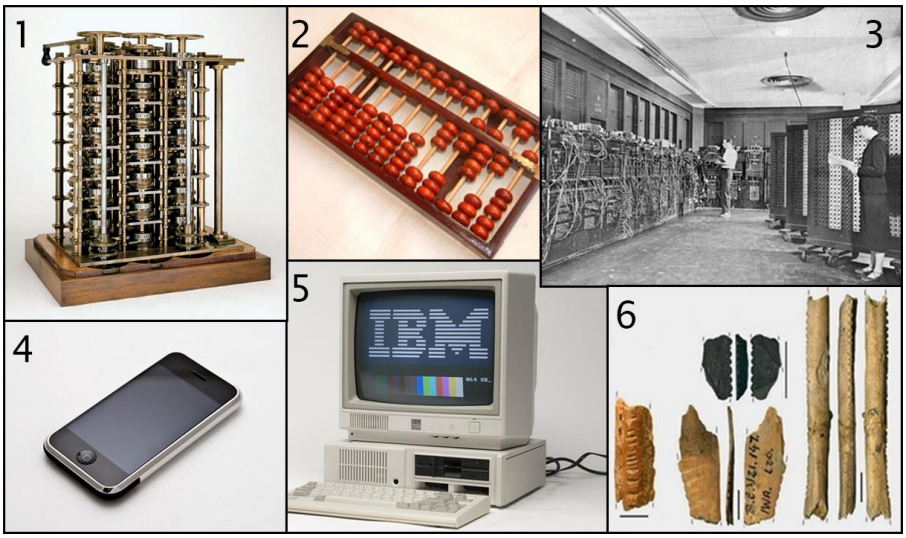
What is the Purpose of Tutorial 2?

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

- Describe how transistors are the basic building blocks of computer chips.
- Using Moore's law, illustrate why computers have dramatically improved their performance over the last decades.
- Name three ways to improve the basic components of computers in the future.

Activity 1 – Counting machines

On the next page are images of various technologies that were designed to help people perform calculations. Can you place them in chronological order and match them to their description?



Write down the image number of the correct computing tool	When the technology was invented
	44,000 BC
	200 BC
	1832
	1945
	1981
	2007

Draw a line to connect to the right name and description

Name	Numbers represented by
Difference engine	Toothed wheels marked with decimal numbers
IBM Acorn	Small electronic switches called transistors
Notched bones	Tally marks on bones
Apple iPhone	Small electronic switches called transistors
Abacus	Beads
Eniac	Large electronic switches called vacuum tubes

Activity 2 – Why do computers use 1s and 0s?

The video "Why Do Computers Use 1s and 0s?" explains binary and how computers use transistors to count. Answer the following questions about the video.

a) Name three systems of counting.

1. _____

2. _____

3. _____

b) What is a transistor?

_____

_____

c) How can we use transistors to represent information?

_____

_____

_____

d) Write a short paragraph explaining why modern smartphones have a huge number of transistors in them.
Words to include in your answer may be: calculations, information, switch.

_____

_____

_____

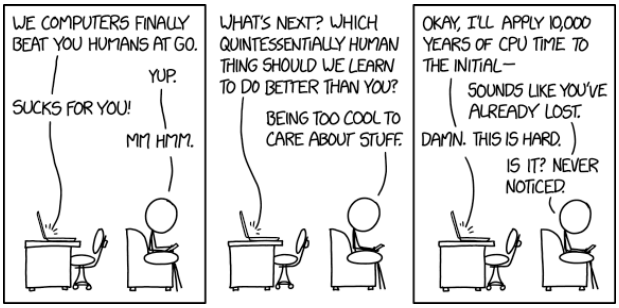
_____

_____

_____

_____

_____



Activity 3 – Moore's law

The size of microprocessors has drastically decreased over the past decades. Moore's law states that the number of transistors on chips double roughly every two years. This historical development has resulted in CPUs and memory improving at exponential rates over the last decades.

Discuss with your neighbour the implications of Moore's law and complete the following activity together.

a) Look at the graphs in Figures 1-3 and determine what other properties of computers have changed over time. Then complete the table below.
   i. In column 1, state what other properties of computer chips may have improved over time,
   ii. In column 2, state some of the technological challenges these improvements may have posed.
   iii. In column 3, state potential solutions scientist may have come up with to tackle these challenges.

   Note: the scale on the y-axis is exponential. This means that for every tick you go up, the value you read out increase by a factor of 10. Exponential graphs are often used to show rapid growth.

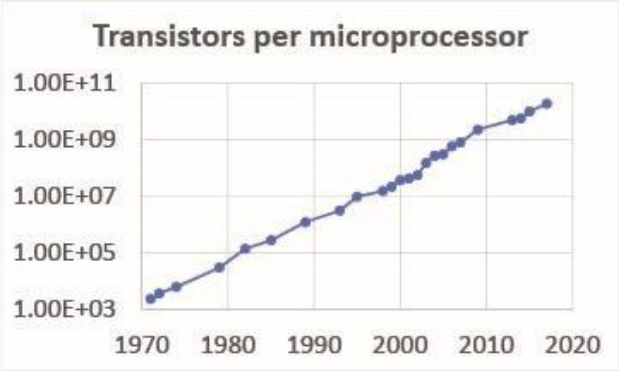


Figure 1: Number of transistors which fit onto a microprocessor over the period 1970-2020.

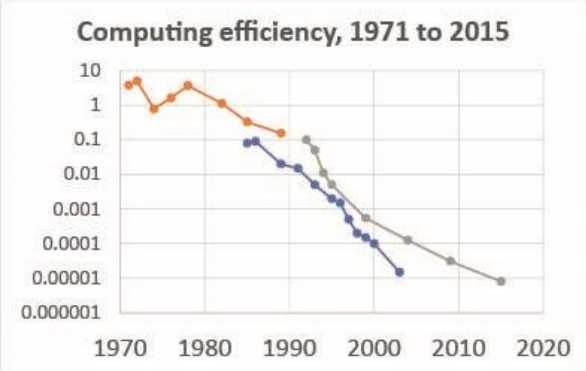


Figure 2: Computer processing efficiency over the period 1971-2015. This is the energy (in Watts) it takes to process a million instructions per second (MIPS)

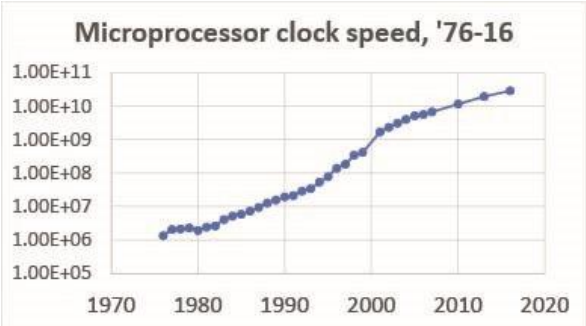


Figure 3: Clock speed of microprocessors over the period 1976-2016. Clock speed is the number of pulses a processor can generate per second (in Hertz), which sets the speed at which the processor performs calculations.

Property that has improved over time	Technological challenge	Potential solution
Size of transistors / microprocessors		

b) State at least two ways researchers and engineers can improve chips to continue Moore's law in the future.

1. _____

_____

_____

2, _____

_____

_____

c) Write one paragraph about the consequences of Moore's law for our current society. Include the follow points:

i. State Moore's law.
ii. State how Moore's law has improved the technology we all have access to.
iii. Give examples of where in society this has had an impact and what that impact has been.

_____

_____

_____

_____

_____

_____

_____

_____

_____

Tutorial 2 Notes

Homework assignment

Before Tutorial 3, check the following points.

- ☐ Update the Subject Vocabulary table with example sentences, based on what you have learned during Tutorial 2.
- ☐ Answer the following question:
  - What was the most surprising or interesting information you learned during Tutorial 2? Why was this surprising or interesting?

_____

_____

_____

- ☐ Compare the success criteria for the final assignment to the content of Tutorial 2 and answered the following question:
  - Which success criteria are you now able to address?

_____

_____

_____

- ☐ Design two questions you might ask to improve your understanding of the content of Tutorial 2.
  - Question 1:

_____

_____

_____

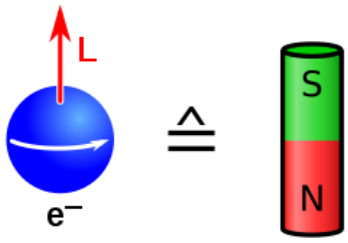
  - Question 2:

_____

_____

_____

Tutorial 3 – Spinning electrons



What is the Purpose of Tutorial 3?

By the end of the tutorial, pupils will be able to:

- Argue whether an observation is a classical or a quantum mechanical phenomenon.
- Explain the link between electron spin and permanent magnets

Activity 1 – Weird observations

Researchers are investigating unknown objects/things labelled "Q"-"X". In the table below, rate on a 1-4 scale the weirdness of their observations.

Weirdness Rating Scale

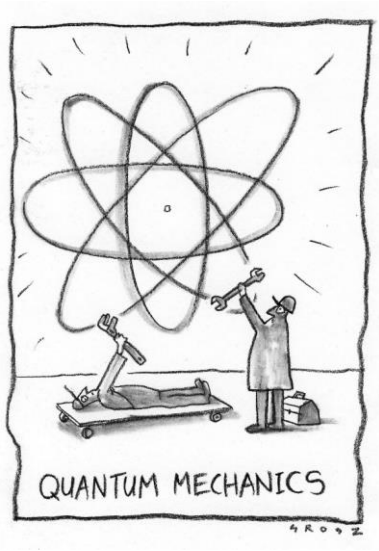
1. So normal, it's boring.
2. Believable
3. Is that possible?
4. Crazy!

Alternative rating: choose a suitable emoji to rate the observation.

Object/thing	*Observation*	*Rating*
Q	"Q" is dropped from a building. It hits the ground directly below where it was dropped.	
R	The researchers place "R" in a closed space. A few moments later, "R" is found to be outside of the closed space.	
S	A handful of "S" is weighed. Each "S" has a similar but slightly different mass.	
T	"T" is so small, it does not have a volume.	
U	A tracker is attached to "U". This allows the researchers to know the speed and location of "U" at any point in time.	
V	"V" has a circular orbit. It travels that orbit both in the clockwise and anti-clockwise direction at the same time.	
W	The researchers measure the speed of "W". As they improve the precision of their measurement, they find it impossible to learn where "W" exactly is.	
X	There are two "X", called X1 and X2. One researcher places X1 in a box and takes it to the moon, while X2 stays on earth. When the researcher opens the box on the moon, it is impossible for her to find out if it is X1 or X2 inside that box.	

Activity 2 – Quantum mechanical properties

Quantum mechanics describes physical phenomena which may be counterintuitive, because they play a role at a scale we mostly do not experience in everyday life.



a) At small scales, physical properties are often quantised. Explain in your own words what that means.

b) Give two examples of quantisation.

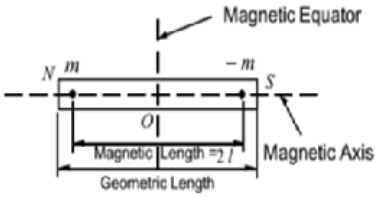
1.

2.

c) What is a superposition in quantum mechanics?

d) Write down two quantum mechanical phenomena and argue why these phenomena are quantum mechanical in nature.
Words to use in your answer: quantum mechanics, classical physics, deterministic, probabilistic.

Activity 3 – Electrons in a magnet



The magnetic dipole moment of a bar magnet with North pole N and South Pole S is given by:

$M = m \times 2l$

The bar magnet in the drawing has magnetic length $2l$ = 10 cm and pole strength m = 100 A·m.

a) What is the magnetic dipole moment?

b) This bar magnet has dimensions 12 × 2 × 2 cm. What is its volume?

c) How many atoms are there in this bar magnet? Use the following formula:

$$n = \frac{N_A \times \rho \times V}{m_a}$$

Use Avogadro's number $N_A = 6.02 \times 10^{23}$ mol^{-1} ;
The density of Cobalt ρ = 8.9 g / cm^2 ;
The volume of the bar magnet V ;
The atomic mass of Cobalt m_a = 59 u.

d) How many electrons are in this bar magnet? Use the image to help you.

					5 B
					13 Al
26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga
44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In

e) Electrons can be imagined as tiny bar magnets with a magnetic dipole moment of $\mu_B = 9.27 \times 10^{-24}$ A·m^2. This constant μ_B is called the Bohr Magneton. If all electrons would contribute to the magnetic dipole moment of the much larger bar magnet – in other words, if we would add all the individual Bohr Magnetons together – what would be the total magnetic dipole moment in the bar magnet?

f) Why is this number much bigger than the answer you found under a)?

g) "Electron spin is the key to understanding magnetic materials." Explain what that sentence means.

Activity 4 – A spin on previous lectures

After finishing the activities 1-3 of Tutorial 3, we are now in the position to apply our new knowledge to previous Tutorials. Answer the question below.

a) Which properties of graphene do you think require knowledge of quantum mechanics to fully understand? For each property you list, explain in one or two sentences why you think quantum mechanics plays a role.

Words to include in your answer may be: Nanoscale, atom, electron, photon.

b) The way electron spin behaves can be described by quantum physical laws. Why would knowledge of the laws describing electron spin be important when we want to advance computer technology in the way described by Moore's law?

Words to include in your answer may be: Electron spin, nanoscale, magnetism, data storage, design.

Tutorial 3 Notes

Homework assignment

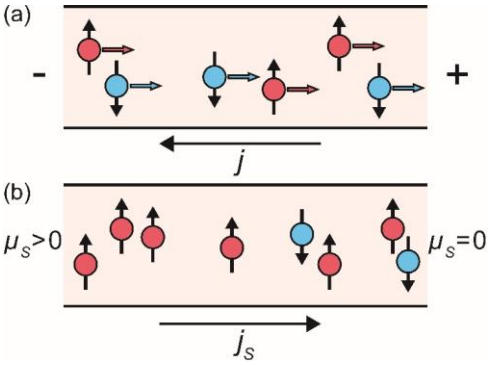
Before Tutorial 4, check the following points.

- ☐ Update the Subject Vocabulary table with example sentences, based on what you have learned during Tutorial 3.
- ☐ Answer the following question:
  - What was the most surprising or interesting information you learned during Tutorial 3? Why was this surprising or interesting?

- ☐ Compare the success criteria for the final assignment to the content of Tutorial 3 and answered the following question:
  - Which success criteria are you now able to address?

- ☐ How would you explain quantum mechanics to your parents or friends? Write a paragraph you could read to someone you know well in which you explain in your own words what quantum mechanics is. Use your new knowledge and feel free to look on the internet to find texts or videos about quantum mechanics to help you.

Tutorial 4 – Spintronics



What is the Purpose of Tutorial 4?
By the end of this tutorial, you will be able to:

- State the definition of spintronics.
- Calculate spin relaxation length in various materials.
- Give the main reasons why spin currents are so short-lived.
- Argue why graphene is such a promising material to be used in spintronic circuits.

Activity 1 – Refresh questions

Fill in the blanks below.

Word bank:
switches batteries hard drive processors magnets electronic optical direction spin-up spin-down topspin two three bytes bits on off

Graphene has many fascinating properties. An example of an _____ property of graphene is its *low/high* electrical resistance.

Electron spin is a *discrete/continuous* quantity. It can have _____ different directions. These directions are called _____ and _____.

Transistors are the basic building blocks of _____. They are little electronic _____, used to represent units of binary information called _____. Transistors represent the numbers 0 and 1 by switching between _____ and _____.

The 0s and 1s of a computer can be stored in its memory, on the _____. Stored bits are represented by small _____ which change their _____ when changing between 0s and 1s.

Activity 2 – Spintronics

During the lecture, you have learned how electrical currents can be spin-polarised and how spin currents are used in the field of spintronics. Now answer the questions below.

a) State a definition of conduction electrons.

b) Explain why an electrical current is sometimes called a charge current.

c) Are common charge currents, such as those in your electrical appliances at home, spin-polarised? Why, or why not?

d) A current has a spin polarisation of 1%. What does that mean?

e) State two existing application areas for spintronics.

1.

2.

Activity 3 – Spin relaxation properties of different materials

In a given material, the spin relaxation length is given by:

$$\lambda = \sqrt{D\tau}.$$

In this equation:

- λ is the spin relaxation length in metres. It means how far a spin current can travel before spin relaxation takes place and the spin polarisation of the current is lost.
- τ is the spin relaxation time in seconds. It means how long a spin current can exist before spin relaxation takes place and the spin polarisation of the current is lost.
- D is the diffusion coefficient in m^2/s. It means how fast a spin current spreads out through a material.

Other information:

- nm is short for nanometre. 1 nm = 10^{-9} s, or one billionth of a metre, or 0.000000001 m.
- ps is short for picosecond. 1 ps = 10^{-12} s, or one trillionth of a second, or 0.000000000001 s.

a) The spin relaxation time in graphene is 150 ps. Give its value in seconds.

b) The spin relaxation length of aluminium is 6.0×10^{-7} m. Give its value in nm.

c) Scientists have measured some spintronic properties of various materials. Using the formula for the spin relaxation length, complete the table below.

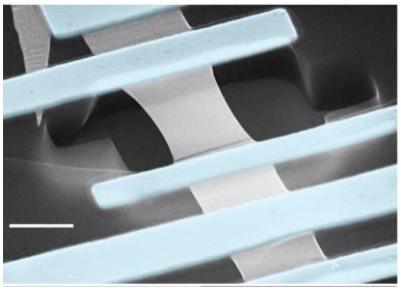
Material	Spin relaxation time (ps)	Diffusion coefficient (m^2 / s)	Spin relaxation length (nm)
Aluminium	100	0.0036	
Copper	11	0.011	
Graphene	150	0.020	
Aluminium (-269 °C)		0.0040	1200
Copper (-269 °C)	42		1000
Graphene (suspended)*	150	0.15	
Graphene (incapsulated)*	1900	0.080	

* Special techniques to create graphene can improve the spin relaxation length.

Normal graphene is placed on a silicon oxide underground or substrate.

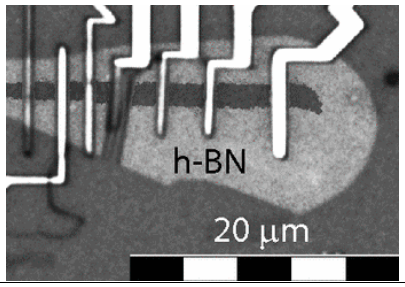
Suspended graphene is graphene without a substrate: it hangs in the air like a bridge. This is shown in the top image, made with an electron microscope.

The blue structures are electrical contacts and the light grey structure is the free-hanging graphene.



Encapsulated graphene is graphene protected by two very flat, insulating layers made of boron nitride. This is shown in the bottom electron microscope image.

The white structures are electrical contacts and the dark structure connecting them is graphene. The light grey structure named h-BN is the boron nitride insulation.



d) Use the values in the table to explain why graphene has good spintronic properties compared to other materials.

Activity 4 – Are spin currents useful?

An electrical current in a wire can travel over distances of metres or even kilometres long. A spin current can only travel over much shorter distances (see activity 3). Write one paragraph about why you think spin currents have the potential to be useful, despite their short travel distance.
Questions you may answer in your paragraph are:

- In what type of devices would spin currents be used?
- What is the typical size of these devices?
- How does the size of these devices compare to the distance over which spin currents can travel?

Tutorial 4 Notes

Homework assignment

Before Tutorial 5, check the following points. You have:

- ☐ Update the Subject Vocabulary table with example sentences, based on what you have learned during Tutorial 4.
- ☐ Answer the following question:
  - What was the most surprising or interesting information you learned during Tutorial 4? Why was it surprising or interesting?

_____

_____

_____

- ☐ Compare the success criteria for the final assignment to the content of Tutorial 4 and answered the following question:
  - Which success criteria are you now able to address?

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_____

- ☐ Which concept you learned today was the most difficult to understand and why?

_____

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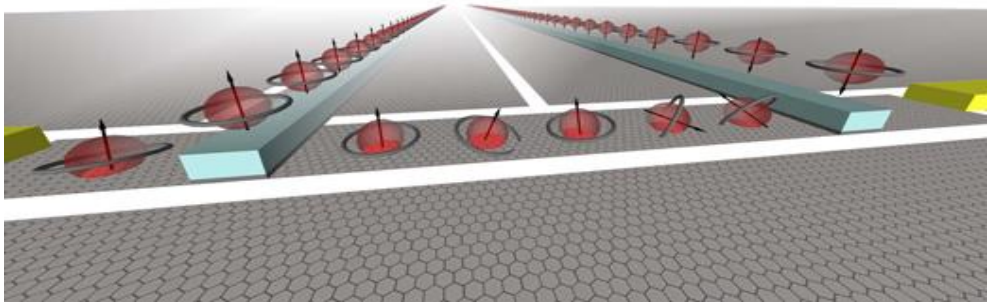
Tutorial 5 – Spintronics and the future of computer chips.



What is the Purpose of Tutorial 5?

By the end of the tutorial, you will be able to:

- Describe some of the requirements of spintronics materials and devices.
- Formulate requirements for future research in spintronics.
- Argue whether you think graphene is a promising spintronic material.

Activity 1 – Refresh questions

Word bank:

spin-polarised classical unbalanced equal quantum mechanical travel randomise charge magnet spin-up spin-down spin current spin relaxation length spin diffusion coefficient

Fill in the blanks below and answer the question that follows.

Electron spin is a _____ property of electrons which makes them behave like a _____. Electron spin can point in two directions called _____ and _____.

An electrical current is _____ when the number of spin-up and spin-down electrons is _____. Such a current is called a _____.

The tendency for spins to _____ after some time is called spin relaxation. The typical distance over which spins can _____ before spin relaxation happens is called the _____.

Activity 2 – Is graphene the future of computing?

Read the article excerpt below and answer the questions that follow. This is a real scientific article from the peer-reviewed journal Science. These articles can be difficult to read, but you are now equipped to understand much of the information given in this article.

REVIEW

Spintronics: A Spin-Based Electronics Vision for the Future

By: S. A. Wolf, D. D. Awschalom, R. A. Buhrman, J. M. Daughton, S. von Molna´r, M. L. Roukes, A. Y. Chtchelkanova, D. M. Treger

This review describes a new paradigm of electronics based on the spin degree of freedom of the electron. Either adding the spin degree of freedom to conventional charge-based electronic devices or using the spin alone has the potential advantages of nonvolatility, increased data processing speed, decreased electric power consumption, and increased integration densities compared with conventional semiconductor devices. To successfully incorporate spins into existing semiconductor technology, one has to resolve technical issues such as efficient injection, transport, control and manipulation, and detection of spin polarization as well as spin-polarized currents. Recent advances in new materials engineering hold the promise of realizing spintronic devices in the near future. We review the current state of the spin-based devices, efforts in new materials fabrication, issues in spin transport, and optical spin manipulation.

Until recently, the spin of the electron was ignored in mainstream charge-based electronics. A technology has emerged called spintronics (spin transport electronics or spinbased electronics), where it is not the electron charge but the electron spin that carries information, and this offers opportunities for a new generation of devices combining standard microelectronics with spin-dependent effects that arise from the interaction between spin of the carrier and the magnetic properties of the material.

Traditional approaches to using spin are based on the alignment of a spin (either "up" or "down") relative to a reference (an applied magnetic field or magnetization orientation of the ferromagnetic film). Device operations then proceed with some quantity (electrical current) that depends in a predictable way on the degree of alignment. Adding the spin degree of freedom to conventional semiconductor chargebased electronics or using the spin degree of freedom alone will add substantially more capability and performance to electronic products. The advantages of these new devices would be nonvolatility, increased data processing speed, decreased electric power consumption, and increased integration densities compared with conventional semiconductor devices.

Major challenges in this field of spintronics that are addressed by experiment and theory include the optimization of electron spin lifetimes, the detection of spin coherence in nanoscale structures, transport of spin-polarized carriers across relevant length scales and heterointerfaces, and the manipulation of both electron and nuclear spins on sufficiently fast time scales. In response, recent experiments suggest that the storage time of quantum information encoded in electron spins may be extended through their strong interplay with nuclear spins in the solid state.

[...]

Outlook

To continue the rapid pace of discoveries, considerable advances in our basic understanding of spin interactions in the solid state along with developments in materials science, lithography, miniaturization of optoelectronic elements, and device fabrication are necessary. The progress toward understanding and implementing the spin degree of freedom in metallic multilayers and, more recently, in semiconductors is gaining momentum as more researchers begin to address the relevant challenges from markedly different viewpoints. Spintronic read head sensors are already impacting a multibillion dollar industry and magnetic random access memory using metallic elements will soon impact another multibillion dollar industry. With contributions from a diversity of

countries and fields including biology, chemistry, physics, electrical engineering, computer science, and mathematical information theory, the rapidly emerging field of spintronics promises to provide fundamentally new advances in both pure and applied science as well as have a substantial impact on future technology.

Reference
Science, 16 Nov 2001:
Vol. 294, Issue 5546, pp. 1488-1495
DOI: 10.1126/science.1065389
Read full article at:
https://apps.dtic.mil/dtic/tr/fulltext/u2/a516289.pdf

Questions

a) First, complete the table below, based on your reading. Then, improve your answer based on the group discussion about the future of spintronics

Advantages	Challenges

b) Reflection. The article you read was written in 2001, a few years before the discovery of graphene. How do you think the discovery of graphene might have changed the outlook for spintronics?

c) Reflection. Imagine that in a few years from now, a different chip technology is developed, enabling chips that are faster and more efficient than graphene spintronic chips. In that scenario, do you think the research in this field was a waste? Why or why not?

Tutorial 5 Notes

Final assignment

Write a 1500-2000 word essay in which you answer the following question:

What are the promises and challenges of graphene as a spintronic material in computer chips of the future?

Success criteria

Your essay should address the following points:

- The importance of the discovery of graphene.
  - Describe the structure and properties of graphene.
  - Argue why graphene is an important scientific discovery.
  - Describe some potential applications of graphene.
- Moore's law and the challenges of future computer chip design.
  - Explain how transistors form the basic building blocks for computers.
  - Illustrate using Moore's law how computers have improved over the last decades.
  - Formulate some of the requirements for future computer chips.
- An explanation of spintronics.
  - Explain what the concept of electron spin means.
  - Explain what a spin current is.
  - Argue why spin currents may be used in future computer chips.
- The requirements for materials to be suitable for spintronics devices.
  - Explain what spin relaxation is.
  - Argue why a long spin relaxation length is important for spintronic materials.
- The requirements for graphene to become a successful spintronic application.
  - Defend why graphene has such promising spintronic properties.
  - Compare and contrast graphene's advantageous spintronic properties with the challenges which researchers need to overcome to be able to make graphene-based spintronic chips.

Furthermore, your essay should meet the following criteria:

- Correct use of grammar and spelling.
- Follow a clear structure, for example:
  - Introduction paragraph.
  - Body paragraphs which refer to what you have learned during this course. Optionally, you may include other relevant information you have researched yourself, if it matches the narrative of your essay.
  - Conclusion paragraph.
- Use of scientific language and keywords.
- Compelling title.
- Concise language without repetitions.
- Proper use of references (see appendix).

Tutorial 6 – Feedback tutorial

What is the Purpose of Tutorial 6?

- To receive feedback on your final assignment
- To respond to the feedback from your Uni Pathways teacher
- To write targets for improvement on your final assignment

Final assignment feedback from your Uni Pathways Teacher

(Remember to look at the mark scheme to help you understand what you have done well so far, and how you can do even better in your final assignment)

Here are three things that my Uni Pathways Teacher thought I did well in my draft assignment
•   •   •

Here are three things that my Uni Pathways Teacher thinks that I could do to get a higher mark in my final assignment
•   •   •

Tasks from my Uni Pathways Teacher to do during the feedback tutorial to help me improve
•   •   •
My response:

Actions I will take to improve my final assignment after this tutorial…
•   •   •

Hand in date for my final assignment:	

Tutorial 7 – Final tutorial

What is the Purpose of Tutorial 7?

- To receive feedback and a grade on your final assignment.
- To reflect on the programme including what you enjoyed and what was challenging.
- To ask any questions you may have about university.

Final assignment feedback from my Uni Pathways Teacher

Final mark:	University style grade:
Feedback: Here are three things that my Uni Pathways teacher thought I did well in my final assignment • • •	

Here are three things that my Uni Pathways teacher thinks I should remember for when I am doing this kind of study in the future
• • •

University

What questions do you still have about University after taking part in Uni Pathways?
• • •

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 you 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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