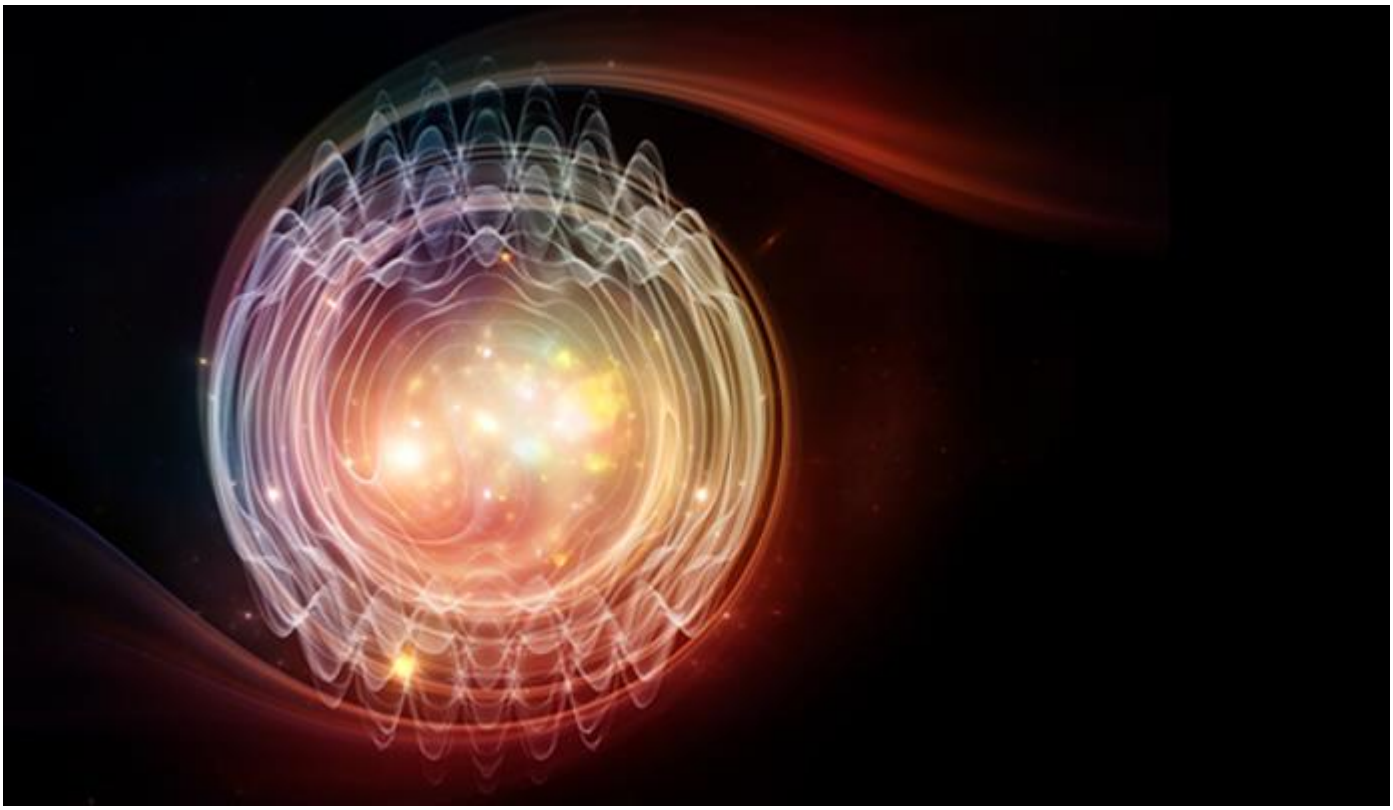

Spintronics – the new electronics revolution?

Key Stage 4 Programme – 2016-2017

Teacher Name Dr Morrison

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	Baseline Assessment	
Tutorial 2	Summarise a research article	
Tutorial 3	Problem sheet	
Tutorial 4	Draft assignment	
Tutorial 5	Final assignment	

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 A-Level
2:1	60-69	Performing to a good standard at A-Level
2:2	50-59	Performing to an excellent standard at current key stage
3rd	40-49	Performing to a good standard at current key stage
Working towards a pass	0-39	Performing below a good standard at current key stage
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 RIS Teacher			
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 teacher 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*

Example

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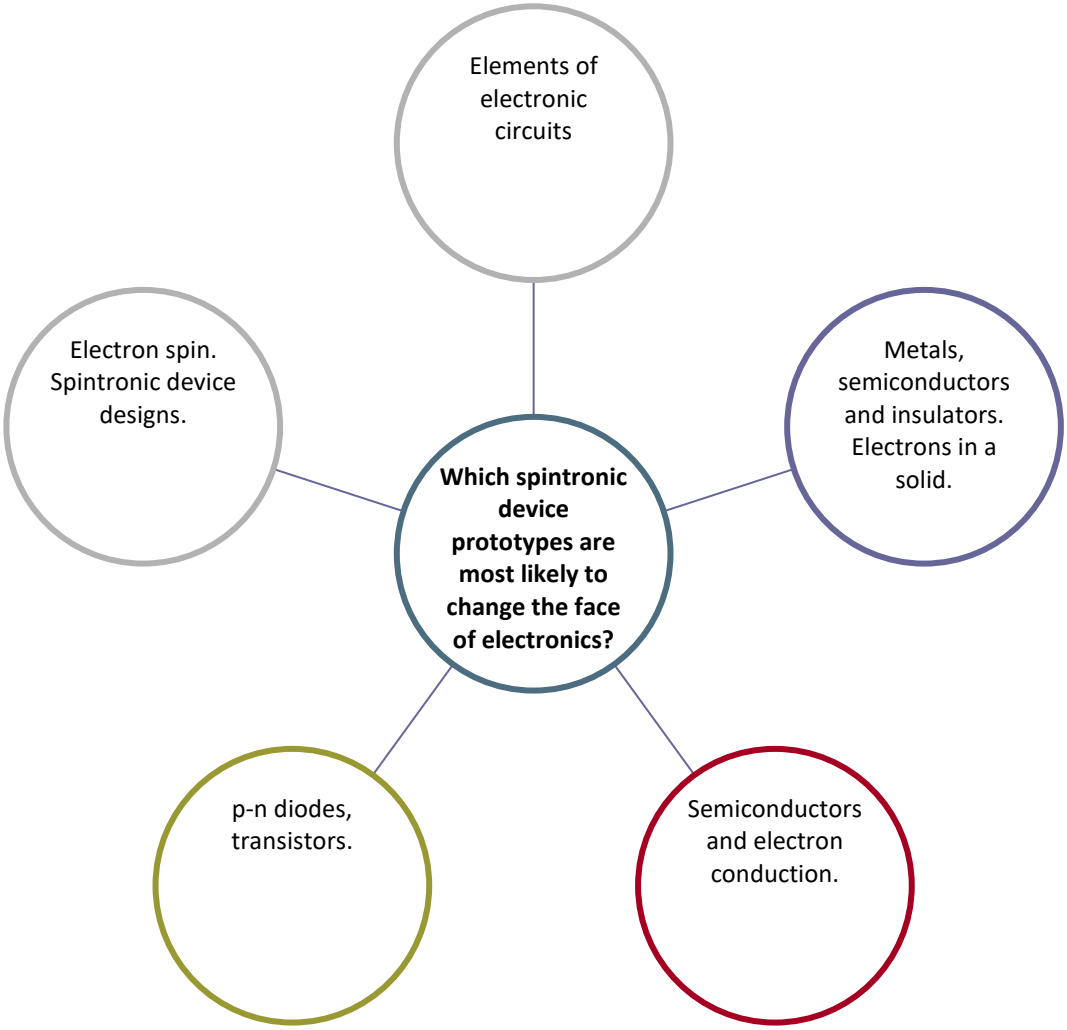
Course Rationale

Electronics have developed at an incredibly fast pace since the earliest computers were invented in the 1940's, leading to personal computers being widely available within 40 years of the first models. More recently, electronic devices can be found in nearly all areas of society, in areas as important as traffic control, power generation and global satellite communication and navigation, as well in mobile phones, tablet computers and games consoles. The industry behind these advancements is a multi-billion dollar concern, that employs thousands of people in the UK and worldwide. Behind all of these advances is the physics of crystalline solids, and their electronic properties, which form the building blocks of computation and memory in computers and electronic devices. Key advances have been made by physicists in the past 70 years, including using the semiconductor silicon to produce transistors, and in data storage based on magnetic materials.

In this course, you will study some of the key physical concepts behind the electronics revolution. Initial tutorials will focus on the basic physical concepts needed to understand why different materials behave differently when a voltage is applied across them, and how their properties can be changed by manipulating their crystal structure and composition. Towards the end of the course, you will learn how to apply these concepts to understanding how modern electronics work, and how they are built. Finally, to link this knowledge to some of the latest research in the area, the field of spintronics will be explored, where magnetic materials are integrated with conventional electronics to allow new and exciting possibilities. You will gain specific knowledge of this branch of physics, with applications in electronic engineering and beyond. Through final, research based tasks, you will develop skills in independent learning and in producing assignments at a similar level to undergraduate university students.

Course Map


Elements of electronic circuits
Electron spin. Spintronic device designs.
Metals, semiconductors and insulators. Electrons in a solid.
Which spintronic device prototypes are most likely to change the face of electronics?
p-n diodes, transistors.
Semiconductors and electron conduction.

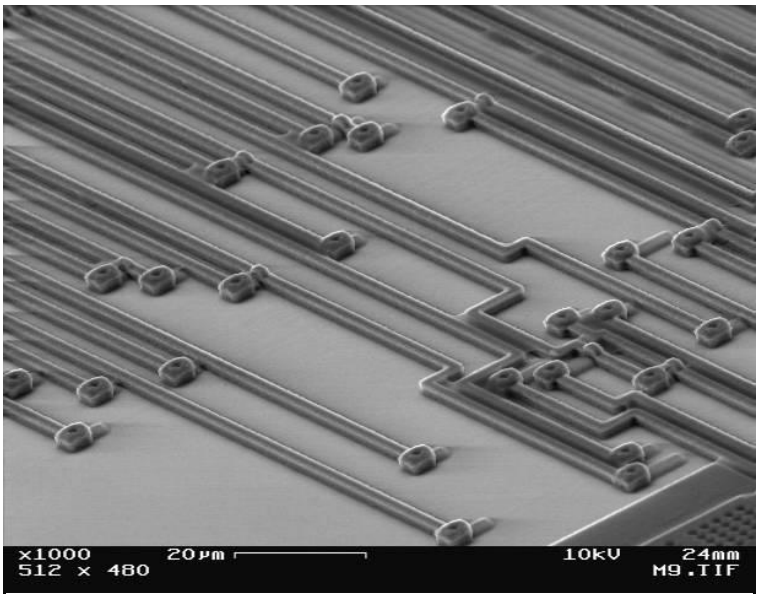
Mark Scheme

Key Skill	1st	2.2
Critical thinking and evaluation	☐ Critical evaluation of the data is systematic and logical – the limitations of the data are explained clearly and most of the main points have been covered. ☐ Appropriate suggestions are made for improvement of the experimental design to increase the functionality or reliability of the spintronic device. ☐ Data from a range of sources is used to compare the results/devices and any differences are discussed.	☐ Critical evaluation of the data covers some of the main points but at times the reasoning is not clear or lacks a logical progression. ☐ Suggestions are made for improvement of the spintronic device, but these can be unrealistic or would not have the desired effect. ☐ A limited range of sources or a single source is used.
Logical reasoning	☐ There is a clear and structured flow of argument with when using logical reasoning. ☐ Arguments and reasoning are expressed with clarity towards an end conclusion. ☐	☐ The structure of arguments may be unclear in places and difficult to follow. ☐ There is a lack of clarity within arguments and reasoning towards the conclusion. ☐
Language	☐ Uses appropriate new and scientific vocabulary correctly and effectively. ☐ Use of new scientific vocabulary shows a detailed understanding of the concepts covered. ☐	☐ Uses simple new vocabulary effectively but struggles with new vocabulary that is more challenging. ☐ Scientific vocabulary may be used incorrectly at times. ☐
Communication	☐ Writing is coherent and organised following a logical sequence. ☐ Almost faultless spelling, punctuation and grammar. ☐ Writing is of an appropriate style for the scientific document and follows stylistic techniques.	☐ At times the writing is poorly organised with a lack of coherent structure. ☐ The spelling, punctuation and grammar are weak in places. ☐ Inconsistent use of style throughout resulting in lack of clarity.

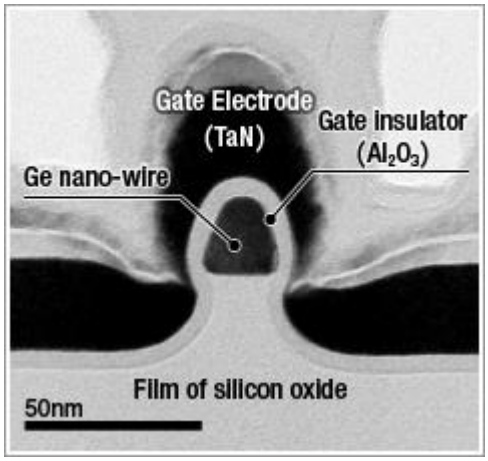
Glossary of Keywords

Word	Definition	In a sentence…
Capacitance	The ability of a system to store electronic charge.	The capacitance of this component is …
Inductance	The property of an electric conductor or circuit that causes an electromotive force to be generated by a change in the current flowing.	The inductance of this coil of wire is …
Transistor	A transistor is a semiconductor device used to amplify or switch electronic signals and electrical power. It is composed of semiconductor material usually with at least three terminals for connection to an external circuit.	A central processing unit comprises many transistors operating in unison to process and manipulate data.
Diode	A diode is an electronic component that conducts primarily in one direction; it has low (ideally zero) resistance to the flow of current in one direction, and high (ideally infinite) resistance in the other.	Semiconductor diodes are the most common type in use today.
Semiconductor	A semiconductor is a substance, usually a solid chemical element or compound, that can conduct electricity under some conditions but not others, making it a good medium for the control of electrical current.	Semiconductor-based electronics make up the vast majority of the electronic devices we use every day.
Electronic band structure	The electronic band structure (or simply band structure) of a solid describes the range of energies that an electron within the solid may have (called energy bands, allowed bands, or simply bands) and ranges of energy that it may not have (called band gaps or forbidden bands).	The band structure of silicon features a band gap that makes it possible to use silicon to make solar cells by absorbing light energy from the sun.
Spintronics	Spintronics (a portmanteau meaning spin transport electronics), is the study of the intrinsic spin of the electron and its associated magnetic moment, in addition to its fundamental electronic charge, in solid-state devices.	Spintronic devices can already be found in electronic devices such as hard disk drives, and are a promising future technology for low power electronics.

Tutorial 1 – The physics of modern electronics



http://www.optics.rochester.edu/workgroups/cml/opt307/spr06/alex/



http://www.yokoyama-gnc.jp/english/works/index.html

Today's Key Question(s):

- Why is studying the physics of electronics so important?
- What are some key examples of electronic components found in everyday electronics?

What is the Purpose of Tutorial 1?

- Introduction to the course and an overview of the content.
- To become familiar with some key examples of modern electronic devices and the physics behind them.

This session will establish the importance of this area of study by focussing on the electronic components that you will be able to explain, by the end of the course, how they work, using physical terminology. We will discuss the basics of electronic circuits using resistors and voltage/current sources, leading into introducing new concepts in electronic components:

Capacitors – can be used to store electronic charge in circuits, either to power devices once the external power source is turned off, or to store charge as part of a 'memory' element.

Inductors – the simplest version is a coil of wire, can be used to make filters in AC electronics, a common example of the use of inductors is in the tuners used to select a frequency (channel) in radio and TV broadcasts. Inductors have an 'inductance' which is proportional to the size of the magnetic field generated by the current flowing in the circuit.

Diodes – pass current in one direction only, blocking current flow in the opposite direction.

Transistors – used in all modern electronics. Allows current flow in the circuit to be turned on or off by using a separate voltage supply to 'gate' the current flow. This switching action enables the logic operations used for computation, allowing bits of information to be manipulated in, for example, the Central Processing Unit (CPU) of a computer.

Today's Homework is:

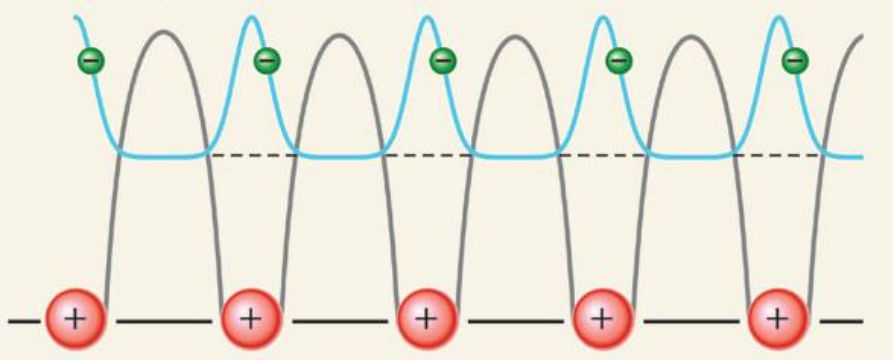
- Baseline Assessment

Homework 1 – Baseline Assessment

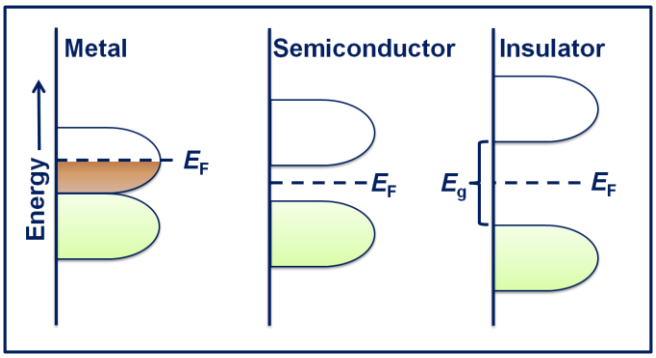
The homework assignment for the first tutorial is a baseline test to see your initial level of attainment in this subject area. The assignment will test for some or all of the subject specific skills that are required later in the final assignment. However, it is shorter than the final assignment and 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 Dr Morrison and yourself to identify where you are at the start of the programme and to help you measure your progress along the way.

Tutorial 2 – Metals, semiconductors and insulators – electrons in solids



1 M Greiner et al., Nature 453, 736 (2008)



L Pan and G Zhu, Perovskite Materials - Synthesis, Characterisation, Properties, and Applications (InTech)

Today's Key Question(s):

- What are the key differences between metals, semiconductors and insulators?
- How do they behave when we apply a voltage across them?

What is the Purpose of Tutorial 2?

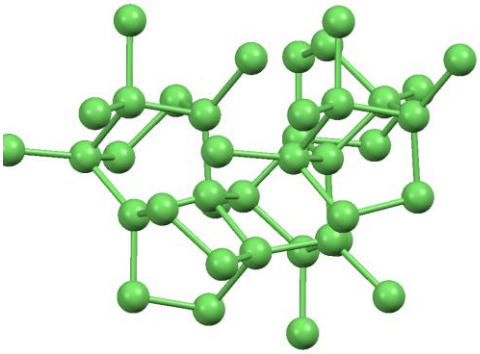
- To introduce the physics of metals, semiconductors and insulators.
- To consider electrons as particles in a potential energy from the nuclei.

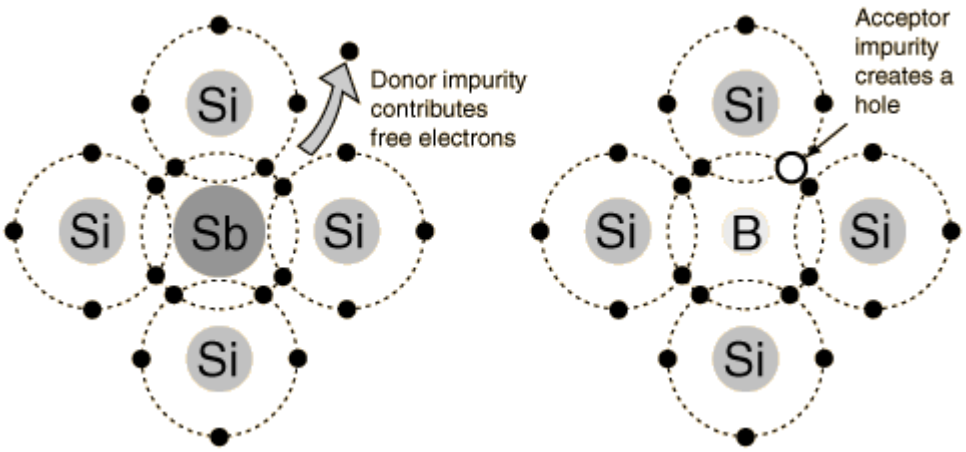
Electrons in solids are confined by the electric potential created by the positive protons in the nucleus. This results in energy 'bands', certain energy ranges that electrons are forced to occupy. Metals, semiconductors and insulators have different energy band structures, that give rise to their electronic properties. In metals the electrons are relatively free to move, and so metals typically have a low electrical resistance. In insulators, there are no available energies at which electrons can conduct, which is another way of saying that the electrons are tightly bound to the electric potential generated by the nucleus. Because of this, insulators do not conduct electricity. Semiconductors are insulators that are very close to being conductors, and a small amount of energy from, for example, light or heat can cause them to conduct more readily. Because of this, semiconductors are excellent for any applications where we need to control the flow of an electrical current such as in computers.

Today's Homework is:

To read an article on semiconductors (provided) to provide background on the specifics of this class of conductive material, and write a short paragraph summarising the key content.

Tutorial 3 – The Physics of Semiconductors





http://hyperphysics.phy-astr.gsu.edu/hbase/solids/dope.html

Today's Key Question(s):

- What makes a semiconductor behave as it does when a voltage is applied across it?
- How can semiconductors be modified to make the building blocks of electronics?

What is the Purpose of Tutorial 3?

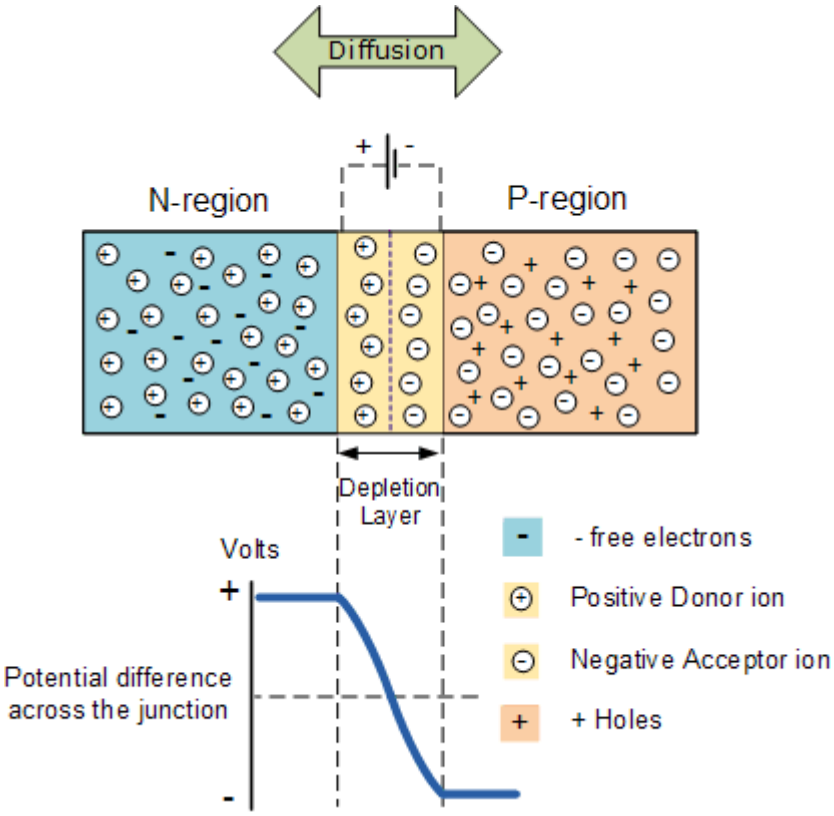
- To study semiconductors in detail.
- To examine how doping semiconductors with other elements can change their conductive properties.

In this tutorial we will focus on semiconductors in more detail. We will look at examples of how adding small amounts of impurities to a semiconductor (such as, for example, antimony (Sb) or boron (B) in silicon) can dramatically change its electrical properties by adding more electrons that can conduct or taking away electrons. This is possible because these impurities have more or less electrons that the semiconductor in their outer shell, and so they either donate an electron or accept (take away) an electron when they bond with the semiconductor. For example, Sb is in group V and so has 1 more electron in its outer shell than silicon (Si) which is in group IV. When Sb bonds to Si this extra electron goes into the free electron 'cloud' and contributes to conduction.

Today's Homework is:

- To complete a short problem sheet comprising problems related to all of the previous tutorials.

Tutorial 4 – Semiconductor diodes and transistors



http://www.electronics-tutorials.ws/diode/diode_2.html

Today's Key Question(s):

- How does a p-n diode work and what happens when a voltage is applied?
- How does a transistor work? What does the 'gate' do?

What is the Purpose of Tutorial 4?

- To learn about semiconductor p-n diodes.
- To study in more detail the physics of transistors.

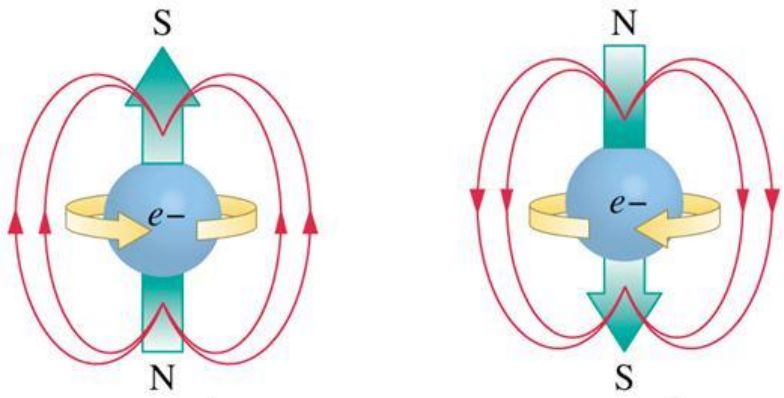
If we dope a semiconductor in two different ways in close proximity, so that one region has an excess of electrons and one has an electron deficit, a 'depletion region' is formed between the two different regions in which the extra electrons combine with the 'positive' (lack of negative) charges. When a voltage is applied to this junction it will act like a diode, passing current in only one direction and opposing current flow in the other.

We will also study transistors in more detail, in particular how a voltage applied to a 'gate' creates an electric field that can be used to either deplete or enhance electrons underneath the gate, resulting in a change in the current flowing underneath the gate. Transistors also use regions that have been doped with impurities to produce specific effects on conduction under the action of the gate.

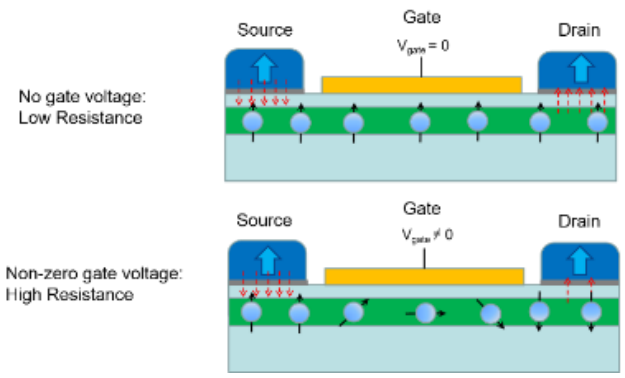
Today's Homework is:

- Begin to draft the final assignment by reading texts and articles and producing a literature review. This will form half of the final assignment.

Tutorial 5 – Spintronics



https://www.princeton.edu/ssp/joseph-henry-project/galvanometer/explaining-the-phenomenon/modern-understanding/



C. Morrison et al., Phys. Status Solidi A (2016) (in press)

Today's Key Question(s):

- What is electron 'spin'? Why is it a useful property? How can we measure it? (qualitative).
- How can spin be used to make spin electronic (spintronic) devices? What advantages/disadvantages do these have compared to charge electronics?

What is the Purpose of Tutorial 5?

- Introduction to electron spin and spin electronics (spintronics).
- Examples of some key spintronic devices and proposed devices.

So far we have discussed standard electronics, which relies on the movement and storage of charge. In this tutorial the concept of spin electronics, or spintronics, is introduced. The electron has two key properties, its charge (negative) and spin, which can be either up or down. Spin is a form of angular momentum, the electron appears to be constantly rotating and this moving charge produces a magnetic field. The direction of the spin (clockwise or anti-clockwise) determines the orientation of this field, and if we picture this as a bar magnet then the 'north' pole will be found at either the top (up spin) or bottom (down spin) of the electron.

Spin electronics can be extremely energy efficient, allowing us to make extremely small and fast electronic devices that produce almost no waste heat. This has obvious advantages for energy saving and for reducing environmental impact.

Today's Homework is:

- Final Assignment

The Deadline is:

Final Assignment

This assignment will be essay based, you will carry out a literature review of the various spintronic devices that have been produced since the field began. You will summarise the key elements of these devices, included the basic mechanism on which they work and the proposed contribution that these devices will make to the next generation of electronics. Finally, you will make a decision on the most promising candidate, using the evidence you have gathered and presented in your literature review. You are expected to use a range of sources, and to reference these sources in the same manner as is typically used by academics in the field. Maximum of 2500 words, excluding references and figures.

The essay will include:

- A summary of the key elements of the spintronic devices that have been researched.
- An explanation using Physics terminology of how the devices work.
- An evaluation of the contribution each device is expected to make to the next generation of electronics.
- A conclusion section where you make a decision on the most promising design, justified by the evidence you have presented.

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.